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AN INVESTIGATION INTO THE EFFECTIVENESS OF HALON 1301 (BROMOTRIFLUOROMETHANE CB₂F₃) AS AN EXTINGUISHING AGENT FOR SHIPBOARD MACHINERY SPACE FIRES

Prepared by

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OFFICE OF RESEARCH AND DEVELOPMENT
SHIPBOARD FIRE AND SAFETY TESTING FACILITY
TEST ADVISORY GROUP REPORT

AN INVESTIGATION INTO THE EFFECTIVENESS OF
HALON 1301 (BROMOTRIFLUOROMETHANE CB₁F₃)
AS AN EXTINGUISHING AGENT FOR SHIPBOARD
MACHINERY SPACE FIRES

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Abstract

A series of large-scale fire tests were undertaken at the U.S. Coast Guard Shipboard Fire and Safety Testing Facility, Mobile, Alabama. These tests were intended to determine the effectiveness of HALON 1301 when used as an extinguishing agent for machinery space fire protection. Pre-burn lengths were varied to determine the effect of fire intensity on the pyrolysis products of the agent. Additionally, discharge times were varied to measure the same effect. Two different systems were utilized in the series; the first system was a nitrogen-super pressurized system, and the second system obtained its design pressure from a heat source. All fires were successfully extinguished. It appears that the volume of pyrolysis products produced from breakdown of the agent is a function of the discharge time rather than of fire intensity.

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Preface and Acknowledgement

This test program was a joint effort between the Ansul Company, the Cardox Division of the Chemetron Corporation, the E.I. Dupont De Nemours Company, and the United States Coast Guard. Initial proposals for a test program were made by Dupont in the early 1960's. After the questions of "why" and "how" were resolved, the question of "where" still awaited resolution. Fortunately, a group of individuals dedicated to the improvement of overall maritime safety had embarked on a program to establish a full-scale shipboard fire and safety testing facility for industrial and government use. The dedication of the U.S. Coast Guard Shipboard Fire and Safety Testing Facility in September 1969 afforded the maritime industry a floating test bed which could be used to foster the development of improvements in maritime safety.

In striving to achieve realistic conditions, the M/V RHODE ISLAND was utilized for this program of HALON 1301 extinguishment tests. Special appreciation is extended to:

- Members of the Advisory Group and its chairmen for the foresight and drive that made the U.S. Coast Guard Shipboard Fire and Safety Testing Facility a reality.
- The individual companies involved in the actual test program. In addition to the support that was extended in the pursuit of this program, the willingness to be among the first users of the facility indicates a strong dedication to furthering the interests of maritime safety.
- The staff of the Shipboard Fire and Safety Testing Facility for working many long and hard hours in preparation for and during the tests that were conducted.
- The staff of the National Bureau of Standards Fire Research Section for providing instrumentation for the test program.
- The Alabama State Docks for providing the Fire Boat LURLEEN for use as backup fire protection.
- The City of Mobile, Alabama Fire Department, in particular Chief Melton and Chief Edwards who provided personnel for the manning of the LURLEEN.

The teamwork exhibited by all the groups was a credit not only to the individuals involved, but also to their respective organizations. It is hoped that through their efforts, the danger of uncontrolled machinery space fire aboard merchant vessels may be severely restricted, and that their efforts will result in the detection, containment, and extinction of such conflagration as illustrated in frontispiece on the next page.

"A FIRE AT SEA CAN RUIN YOUR WHOLE DAY!"



Chapter I

INTRODUCTION

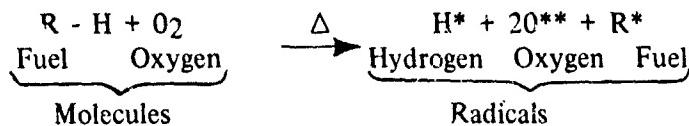
PROGRAM PURPOSE

The program purpose was to:

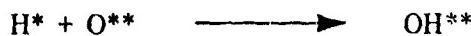
- Determine whether HALON 1301 is an effective extinguishing agent for shipboard machinery space fires.
- Determine what influence varying extinguishing agent concentration, preburn time, and length of discharge time have on the effectiveness of the agent and the level of production of HALON 1301 decomposition products in the machinery space and contiguous areas.
- Determine the feasibility of a heated non-superpressurized HALON 1301 system.
- Establish design parameters for marine installations of HALON 1301 extinguishing systems in machinery spaces.
- Compare HALON 1301 to carbon dioxide as an extinguishing agent.

PROBLEM STATEMENT

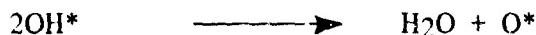
HALON 1301, bromotrifluoromethane (CB_3F_3), is an effective flame inhibitor. Unlike carbon dioxide, which smothers a fire by displacing oxygen, HALON 1301 chemically interacts with the combustion process to inhibit combustion. Although the exact process is unknown, it is postulated that extinguishment or inhibition occurs as follows: "During combustion, it is theorized, fuel and oxygen react through an intermediate hydroxyl radical. First both the fuel and oxygen molecules are decomposed by heat into hydrogen and oxygen radicals:



Next, the two radicals combine to produce hydroxyl radicals:



Finally, two hydroxyl radicals react to produce water:



The final step accounts for the large release of energy, which, since it is fed back into fresh fuel and air, sustains the combustion process; hence the term chain reaction of combustion. The process is interrupted by the introduction of HALON 1301 into the combustion zone. First, the HALON 1301 is also decomposed by heat to give bromine radicals:



The bromine radical reacts with the hydrogen in the fuel to give hydroge. bromide:



The hydrogen bromide then reacts with active hydroxyl radicals to release bromine again:



The bromine radical may now react with more fuel to repeat the process, to remove more active radicals from the fire. Since the two hydroxyl radicals are prevented from reacting directly, the chain reaction of the combustion process is broken." (1)¹ During this combustion interruption process, HALON 1301 decomposes at temperatures in excess of 1000°F to form hydrogen bromide (HBr) and hydrogen fluoride (HF). Both of these decomposition products are toxic in relatively low quantities. Sax (2) considers 50 to 250 ppm of hydrogen fluoride dangerous for short levels of exposure. The state of Pennsylvania has set the occupational limit of exposure to hydrogen bromide at 5 ppm for 5 minutes (3). Presence of these products of decomposition is evidenced by a sharp, acrid, irritating odor.

One of the purposes of this program was to investigate the relationship between length of discharge time, preburn time and the level of these HALON 1301 decomposition products.

The level of hydrogen halides has been attributed by industry to two variables: fire intensity and extinguishing agent discharge time. National Fire Protection Association (NFPA) 12A (4), "Halogenated Extinguishing Agent System HALON 1301 1971" states that there is a direct relationship between production of HF and HBr and the length of agent discharge time and the fire intensity. This relationship has led to the recommendation of coupling automatic detection with automatic discharge (for a total flooding system) with a discharge time of under 10 seconds.

In the planning stage of the test program, it was decided not to couple detection with system activation in order to evaluate the effect of long preburn times on the agent. In other words, by keeping the discharge time constant, the variable of preburn times (hence, fire intensity) could be evaluated.

Another reason for requiring long preburn times is that the traditional philosophy of shipboard machinery space fire protection requires manual release of a fixed extinguishing system, which would permit full fire development before actuation of the system. However, tests were conducted to simulate the concept of rapid detection coupled with automatic activation.

¹Numbers in parentheses designate references in Bibliography, Chapter V.

BACKGROUND

The philosophy of fire protection of a ship's machinery space basically includes the functioning of a multifaceted fire protection system. System components include shipboard personnel, portable fire extinguishers, semiportable fire extinguishers, fixed fire protection systems, and structural fire protection.

Ideally, upon discovery of a fire in machinery space, personnel would attack the fire with either a portable or semiportable fire extinguisher. If these extinguishers were ineffective and hand lines could not be effectively used the ship personnel would abandon the machinery space and activate the fixed fire protection system. This would normally require machinery shutdown, ventilation shutdown, fuel flow stoppage, and closure of all openings into the machinery space. Completion of these tasks can vary from 1 to 15 minutes depending upon the success of the fire fighters. It is necessary, based on present experience and system capabilities, that this procedure be adhered to to isolate the machinery space as rapidly as possible.

It must be understood that a ship at sea is unlike a shore installation where occupants can leave in time of emergency, or where if there is an inadvertent discharge of the fixed fire protection system (due either to false alarms or human error) the local fire protection agency can recharge the system overnight. A ship is an isolated community which is dependent upon a minimum of redundancy for each particular function performed.

NOTE

The preceding discussion should not be interpreted as unqualified adherence to the stated fire protection philosophy; rather, the discussion should serve as an explanation to interested personnel of the principles and precepts that have shaped current policy.

The advent of fully automated machinery spaces, by necessity, required detection of a fire in its incipient stages. Automatic detection and extinction will have to be extremely reliable to preclude inadvertent and possibly dangerous shutdown of the ship's power plant.

PROGRAM LIMITATIONS

The program was conducted "full scale" to simulate actual conditions aboard ship. Duplicate tests were not possible due to variables such as temperature and wind direction. Variations in fire spread, fuel involvement, and temperature severity throughout the machinery space were noted from test to test; these variations can be attributed to the large scale testing that took place.

REPORT ORGANIZATION

This report collates the results of the testing and states some basic conclusions concerning the results. The report is organized as follows to allow for rapid retrieval of data by interested personnel:

Chapter 1 – Introduction

Chapter 2 – Test Procedure

Chapter 3 – Test Results

Chapter 4 – Summary and Conclusions

Chapter 5 – Bibliography

Chapter II

TEST PROCEDURE

PHYSICAL PLANT

The U.S. Coast Guard Shipboard Fire and Safety Testing Facility centers around the 8500 gross ton T-1 tanker M/V RHODE ISLAND. The tanker is 490-ft long, with a 65-ft beam, and normally operated with an 18-ft draft. Figures 1 and 2 show a general outline and port bow aspect of the vessel.

The machinery space where the fires were built is shown in Figures 3 and 4. The net volume of the machinery space is approximately 100,000 cubic feet. The machinery space is a multilevel configuration with a total of five internal decks formed principally by open gratings.

Ventilation during testing consisted of two 37,500 cfm fans added at the time the vessel was converted to a test facility. These fans provide a powered fresh air supply, through two rectangular (3'0" X 2'6") ventilation ducts extending from the top of the machinery casing, where the fans are located (see Figure 5), to the second deck level of the machinery space. One duct is located at the aft starboard corner of the casing; the other at the forward port corner of the casing. Natural exhaust, with skylights closed, was by means of two 4' 6" X 2' 0" rectangular ducts; one duct on either side of the engine located at approximately engine midlength. Additional exhaust was provided through two rectangular ducts at the opposite corners from the supply ducts previously described. Exhaust, with the skylights open, was by the same means plus the skylights. The skylights, when fully opened provided a free ventilation area of about 50 square feet at the top of the machinery casing.

Measurement of air velocity and direction under the ventilation conditions previously described were made by the National Bureau of Standards. Full results are available for review upon request from U.S. Coast Guard Headquarters (5). The general patterns of air movement are shown in Figures 3 and 4.

FUEL SUPPLY

The fuel used for the machinery space fires was marine diesel with a flash point of 130°F to 150°F. Water was pumped into the machinery space bilges to provide a "platform" for floating the fuel. At the beginning of the tests, approximately 1400 ft² of the 1600 ft² available area was a free surface. After the first fire test, a sea chest valve ruptured and admitted additional water to the bilges. This additional water raised the fuel level so that 100 percent of the 1600 ft² was covered with fuel. The vessel was at a slight port list, therefore fuel was above the deck plates on the port side and below the deck plates on the starboard side. In previous testing aboard ships, i.e., the FT. McHenry tests (6), the fuel was

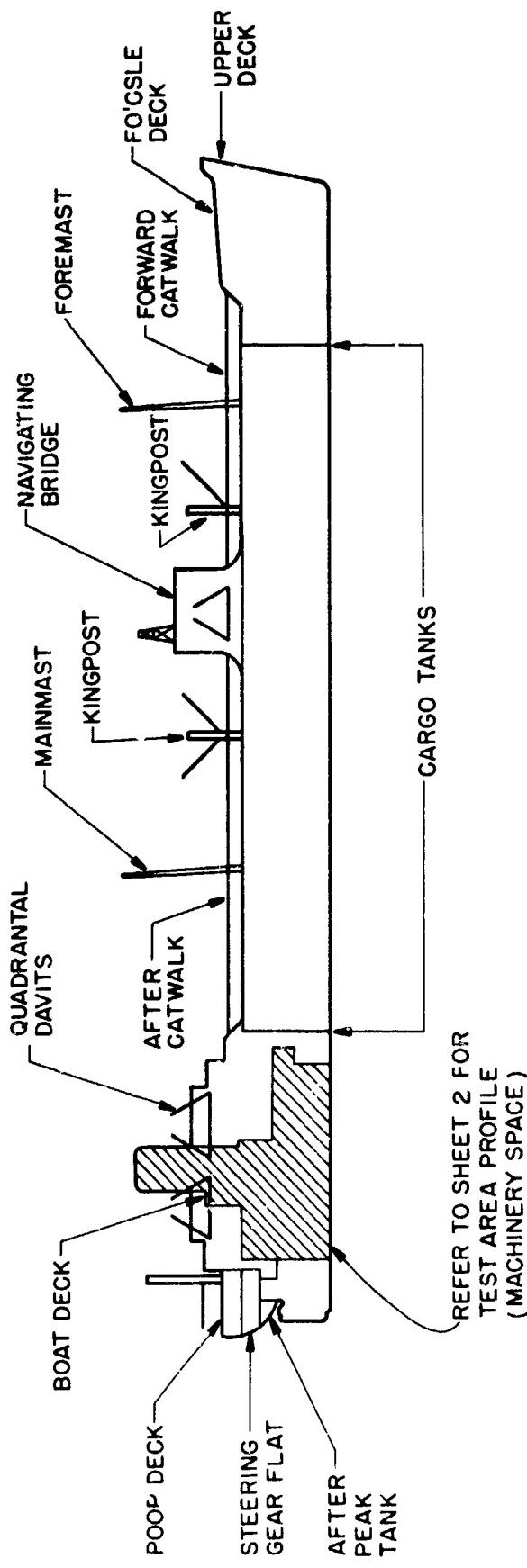
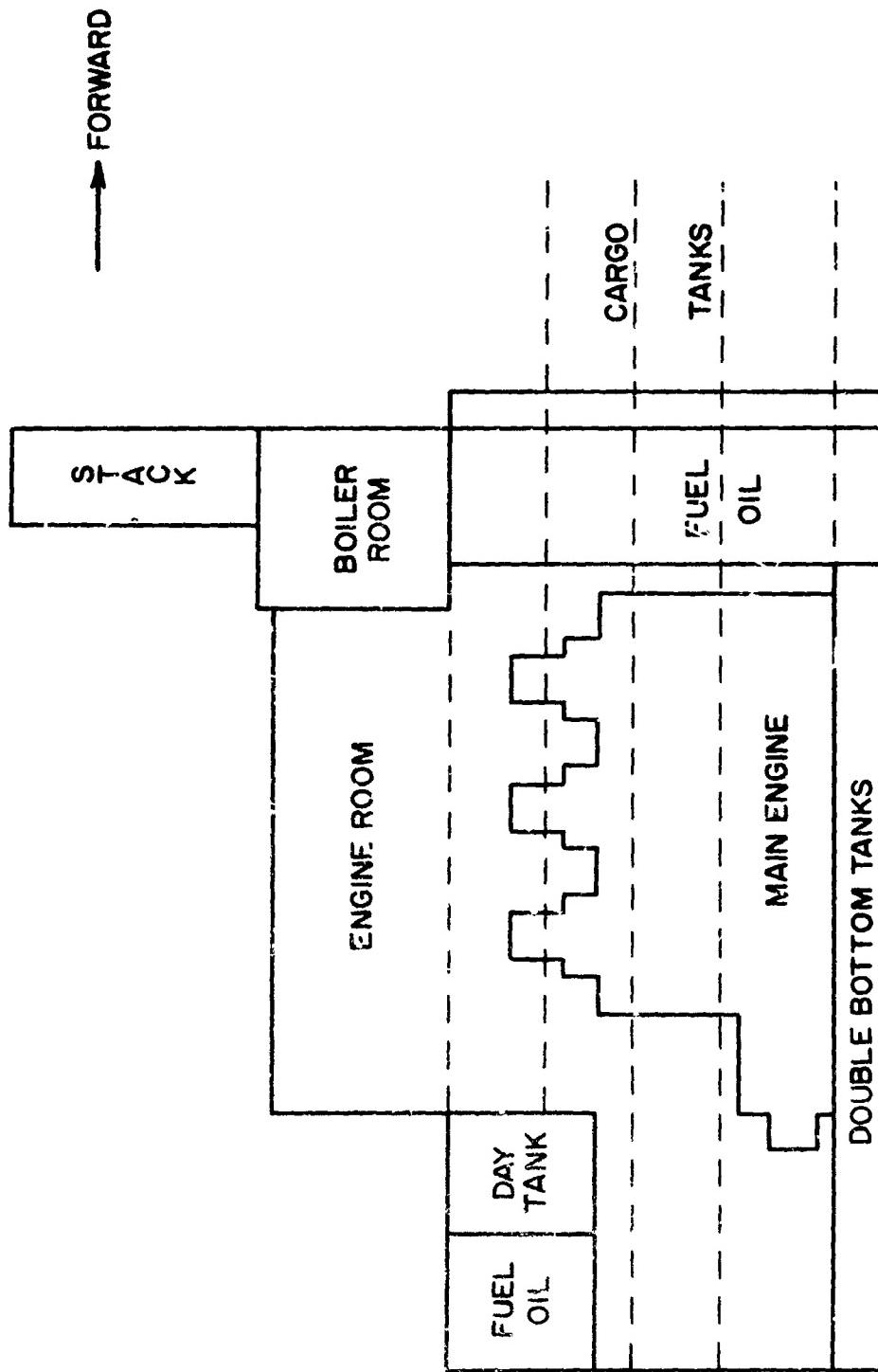


FIGURE 1. GENERAL VESSEL OUTLINE (Sheet 1 of 2).

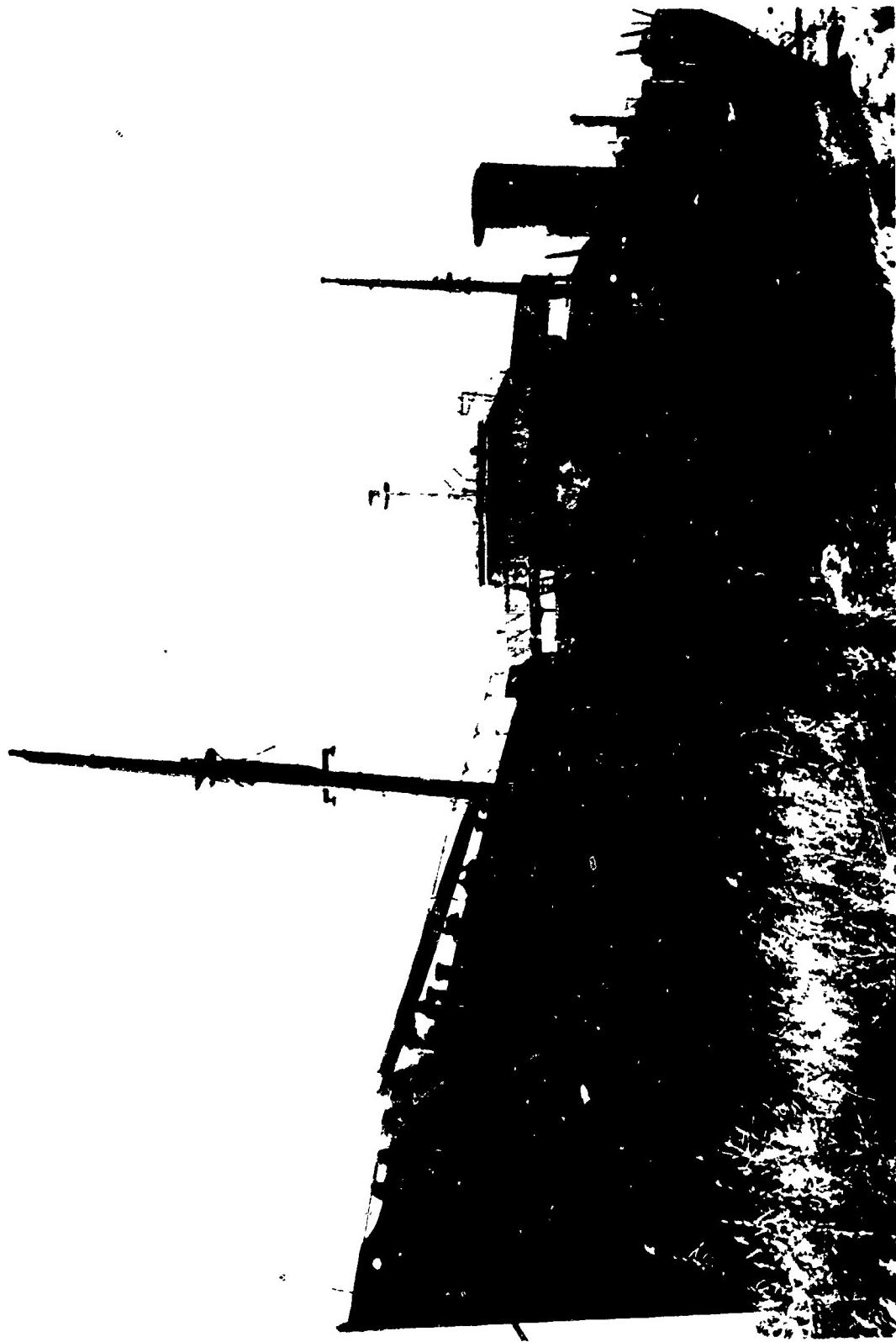
M/V RHODE ISLAND
MACHINERY SPACE PROFILE

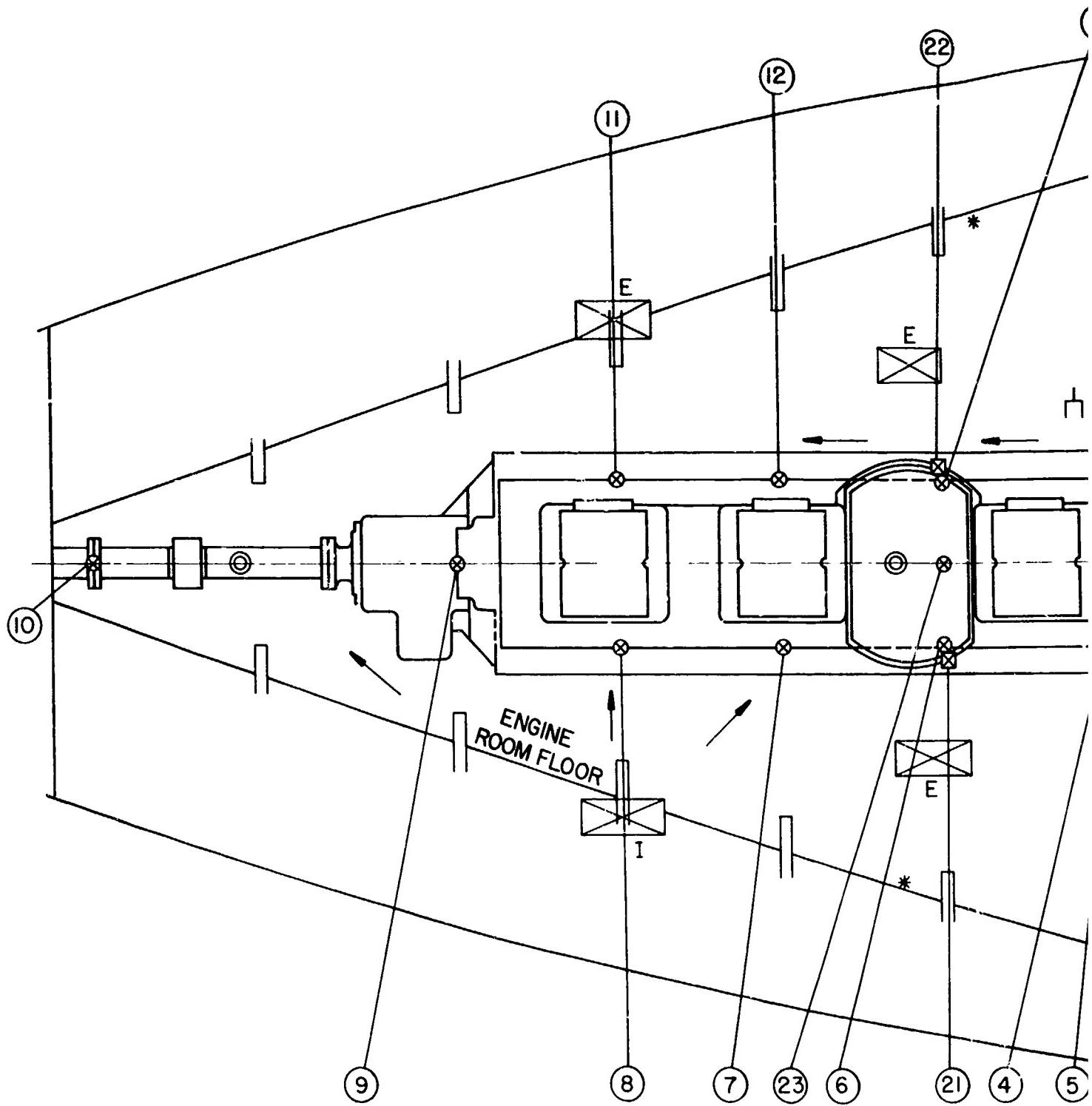


NO SCALE

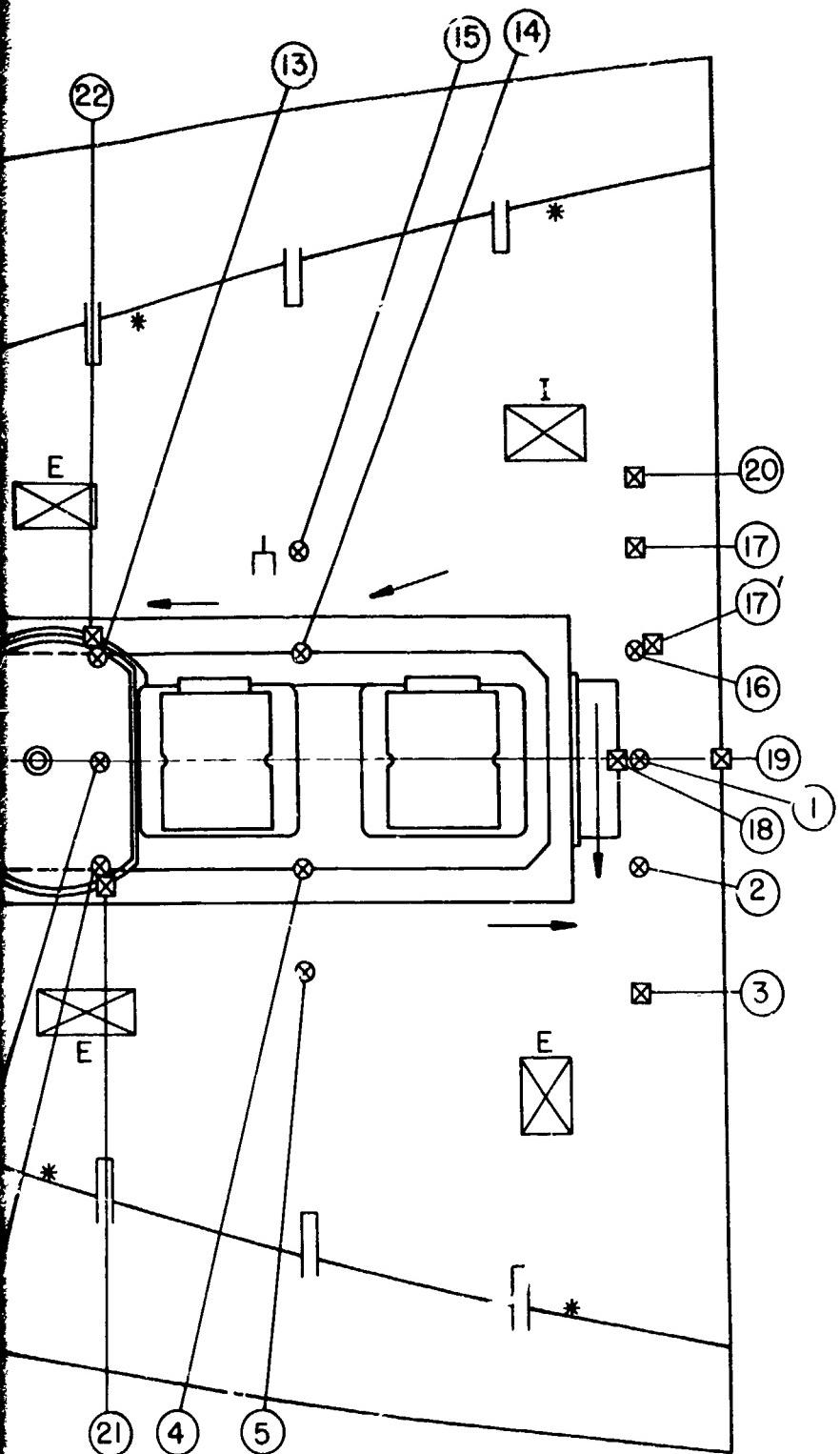
FIGURE 1. GENERAL VESSEL OUTLINE (Sheet 2 of 2).

FIGURE 2. PORT BOW ASPECT VIEW.





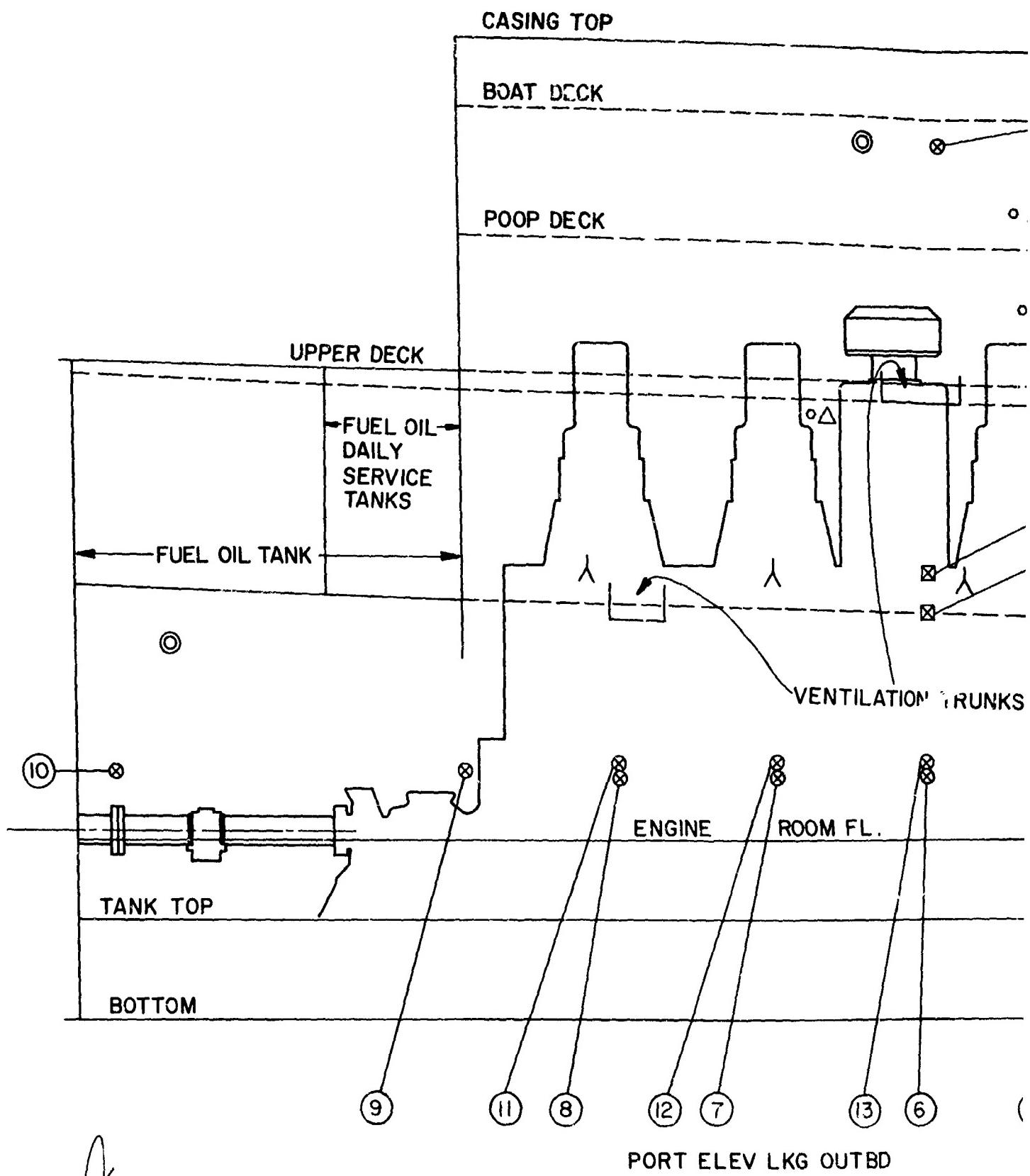
PLAN BELOW SECOND DECK

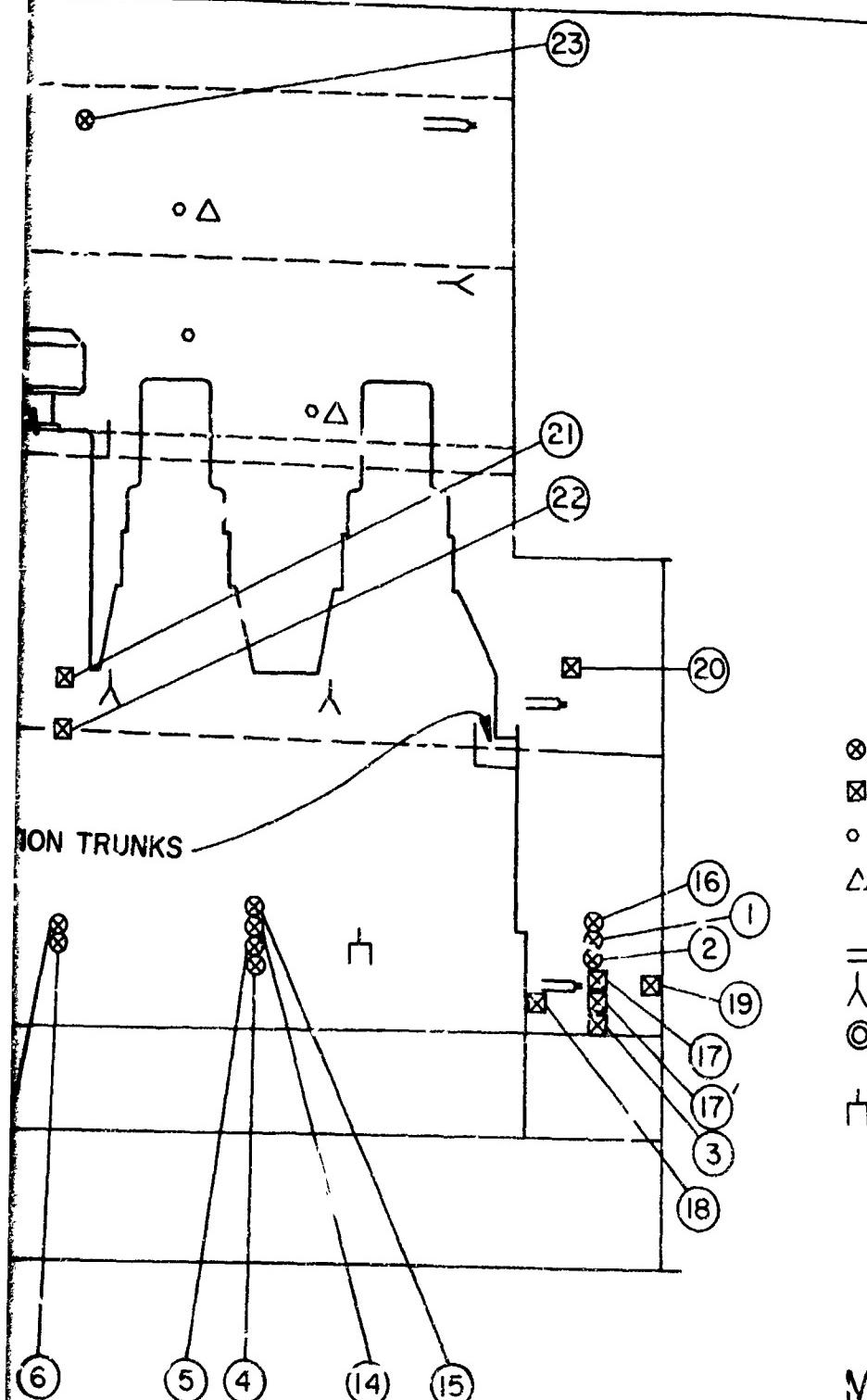


- THERMOCOUPLE NUMBER
- ⊗ THERMOCOUPLES IN AIR
- ☒ THERMOCOUPLES IN METAL
- * IGNITION POINT
- I VENTILATION DUCT INTAKE
- E VENTILATION DUCT EXHAUST
- ARROWS INDICATE GENERAL AIR MOVEMENT
- OXYGEN, CARBON MONOXIDE SAMPLER LOCATIONS
- OIL SPRAY LOCATION

PLAN VIEW
MACHINERY SPACE
M/V RHODE ISLAND

FIGURE 3. PLAN VIEW, MACHINERY SPACE.





- ⊗ THERMOCOUPLE IN AIR
- ⊗ THERMOCOUPLE IN METAL
- HF/HBr SAMPLER LOCATIONS
- △ HALON 1301/CO₂ SAMPLER LOCATIONS
- ⇒ ANSUL HALON 1301 NOZZLES
- λ CARDOX HALON 1301 NOZZLES
- ◎ OXYGEN, CARBON MONOXIDE SAMPLER LOCATION
- OIL SPRAY LOCATION

ELEVATION VIEW
MACHINERY SPACE
M/V RHODE ISLAND

FIGURE 4. ELEVATION VIEW, MACHINERY SPACE.



FIGURE 5. TYPICAL FAN INSTALLATION.

completely below the deck plates. Therefore, the slight list aboard the M/V RHODE ISLAND provided a more severe situation than that previously tested since the fuel surface above the deck plates was even and unbroken due to the lack of obstructions (i.e., valving and piping). The fuel depth was initially measured to be 6 inches with a volume of approximately 6000 gallons. The fire surface burning rate was calculated to be 60 gpm for this area based on the FT. McHenry tests conducted in 1945 (6). If the 60 gpm rate is correct, sufficient fuel existed for 100 minutes of testing. At the end of each test, approximately 700 gallons of marine diesel was added to the machinery space to ensure against limiting the fire duration due to lack of fuel.

To provide a realistic situation, fuel was also sprayed into the machinery space during several of the tests to simulate a ruptured fuel line under pressure. A 50-gpm pump connected to two 55-gallon drums of fuel discharged fuel via two nozzles. Nozzle location is identified in Figures 3 and 4. The two nozzles were connected to 1-inch pipe by a tee and two elbows which directed the fuel downward toward the deck. One nozzle was a straight-stream type which impinged fuel directly onto the deck plates; the other nozzle was a spray type.

IGNITION METHOD

Ignition for the tests was achieved by applying a low-voltage current through a nichrome wire coil to ignite 15-minute railroad flares. The "hot" side of the flares was directed downward into the fuel, and the flares were also wrapped in oil-soaked rags. Four ignition points, identified in Figure 3, were used. Prior to each fire test, the fuel in the vicinity of the ignition points was "primed" with varying amounts of naptha and methyl cel ketone. Five to ten gallons of "primer" was found to start a suitable fire.

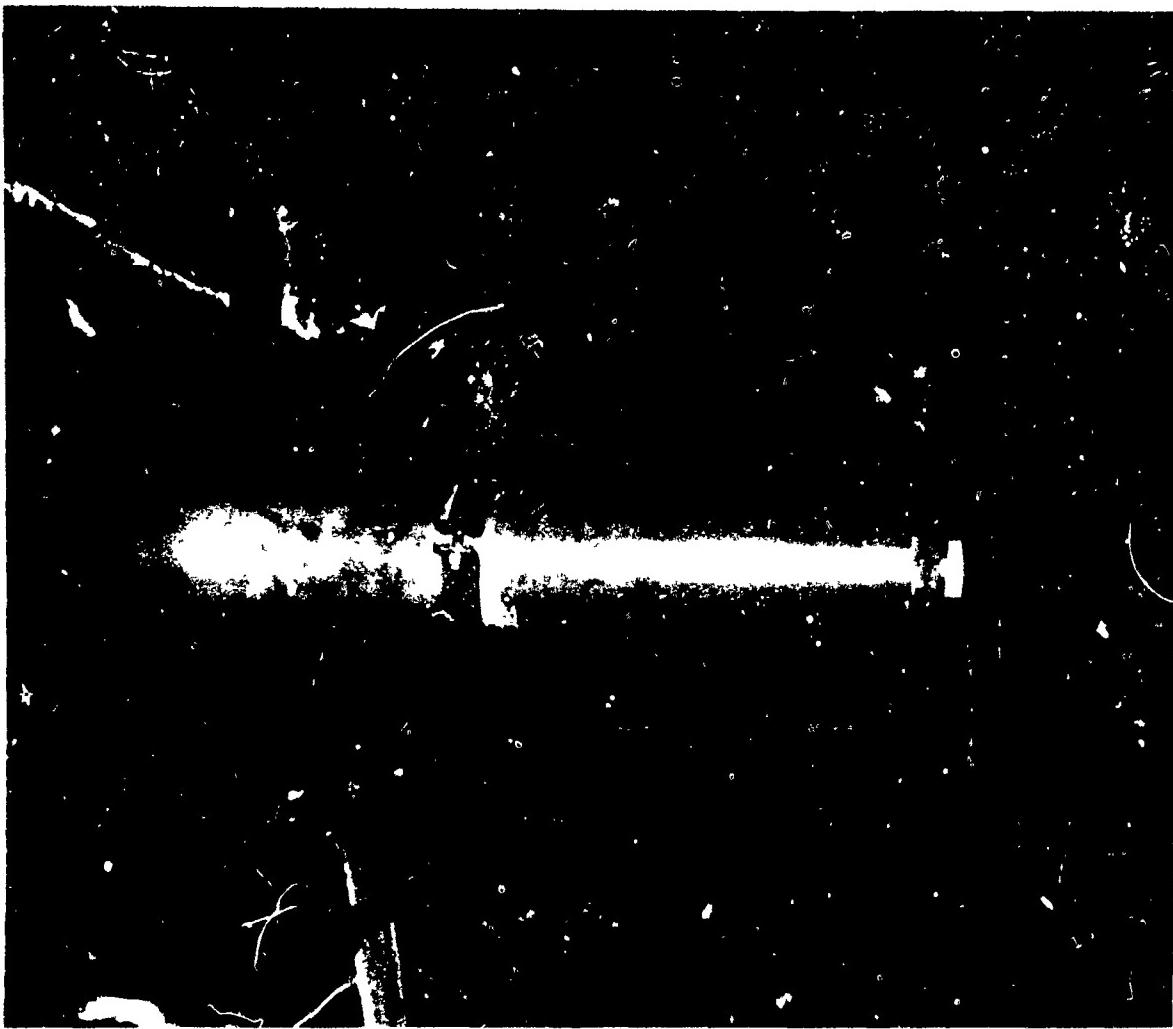


FIGURE 6. TYPICAL NOZZLE INSTALLATION.

SYSTEM DESCRIPTION

NITROGEN SUPERPRESSURIZED SYSTEM. Tests 0 through 4 were conducted utilizing a system designed and engineered in accordance with NFPA 12A. Figure 7 shows the system diagram. Basically, the system consisted of a 31.2-cubic foot ASME unfired pressure vessel (tank), ball valve, 140 feet of pipe, and 5 nozzles located at various levels on the forward bulkhead of the machinery space. A typical nozzle is shown in Figure 6. The tank (see Figure 8) was placed on a large commercial platform scale so that accurate measurement could be made of the HALON 1301 in the tank.

Pressurization Procedure. The procedure for pressurizing the system was as follows:

1. HALON 1301 was transferred from 1-ton containers by an air-driven piston-operated transfer pump.
2. After the design weight of HALON 1301 was transferred from the 1-ton containers to the system tank, the HALON 1301 was superpressurized to 600 psig with nitrogen.

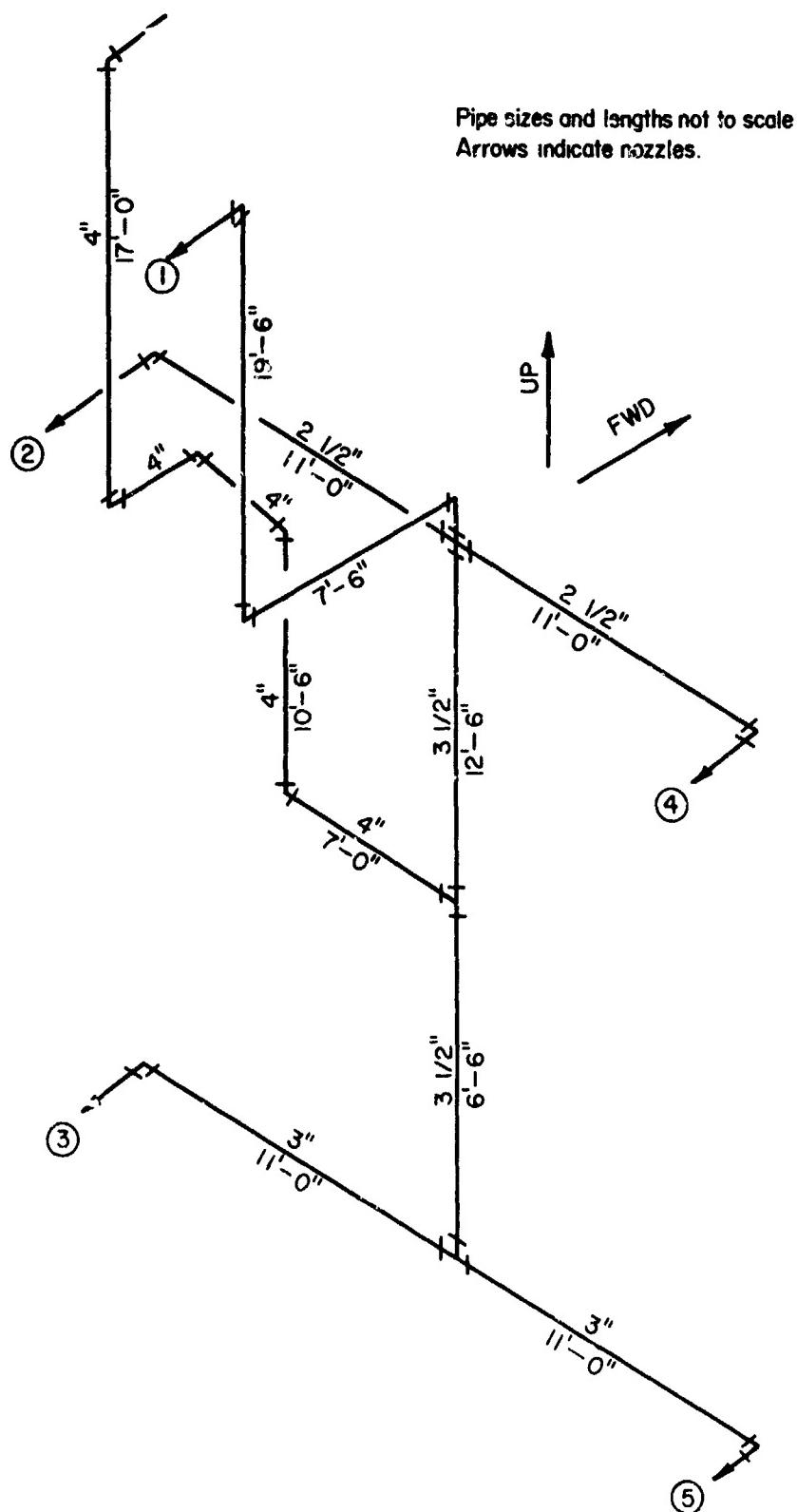


FIGURE 7. NITROGEN SUPERPRESSURIZED SYSTEM DIAGRAM.

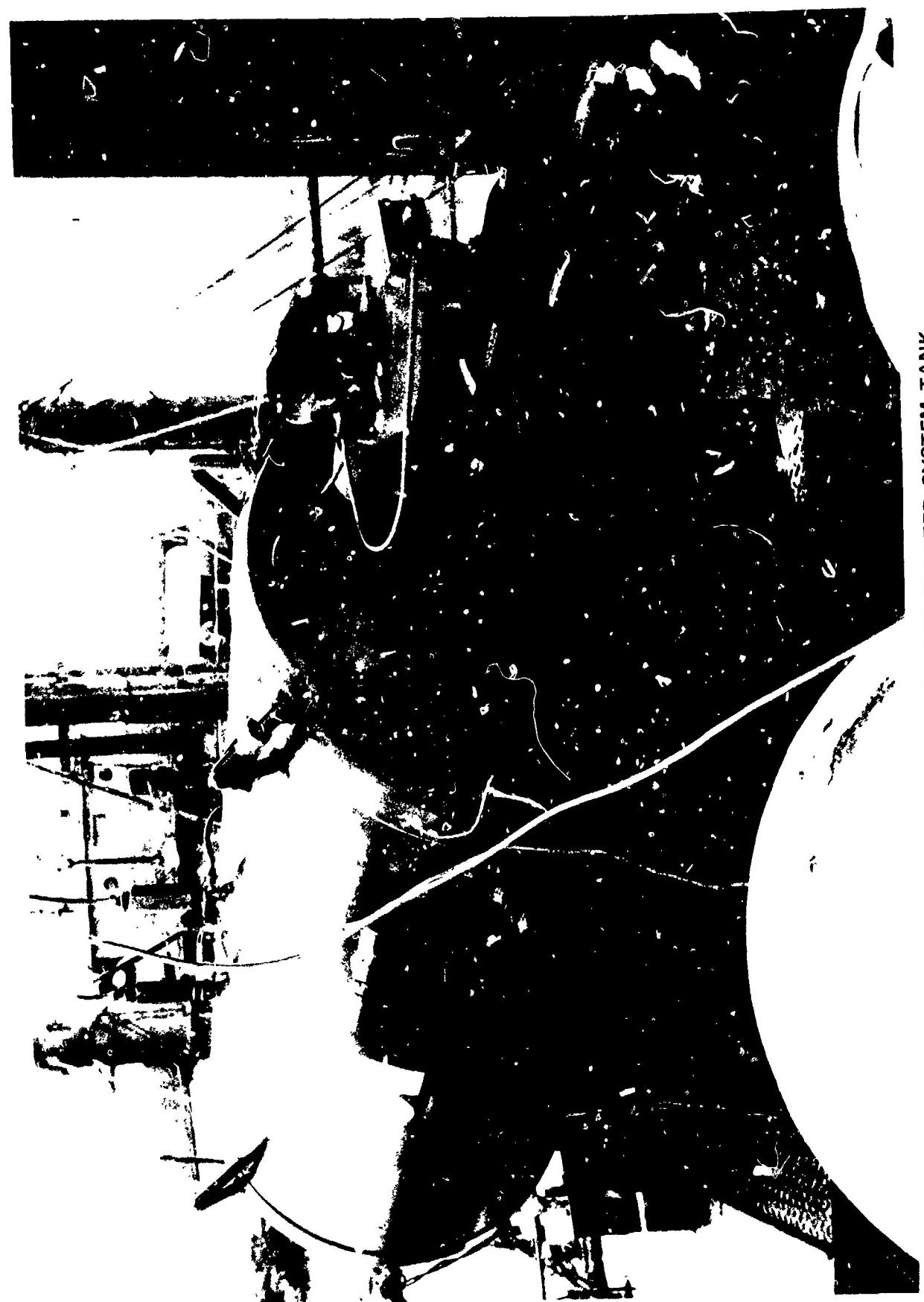


FIGURE 8. NITROGEN SUPERPRESSURIZED SYSTEM TANK.

System Problems. Two problems were encountered with the system:

1. The stainless steel ball valve was impossible to open automatically. Examination of the ball valve revealed corrosion had caused scoring of the valve. Due to the scoring, the valve had to be operated manually.
2. After each fire test, one or more of the air-aspirating devices surrounding the nozzles came loose from its mounting. The combination of discharge forces and different coefficients of thermal expansion between the steel set-screws and the brass nozzles wrenched the devices loose from their mountings. The requirement for air-aspirating devices on nozzles for systems utilizing fast HALON 1301 discharge is currently under investigation.

HEATED LOW PRESSURE SYSTEM. This system was designed to be used in a series of full-scale carbon dioxide extinguishing tests. The heated low pressure system was designed to provide protection of the machinery space in basic compliance with current Coast Guard regulations. A system diagram is shown in Figure 9.

Pressurization Procedure. In this system, HALON 1301 is not superpressurized by nitrogen. An external heater heated the HALON 1301 to produce an autogenous pressure of approximately 300 psi. This method of pressurization is not currently recognized by NFPA 12A due to a lack of test data. The results of the tests utilizing this system should tend to establish the feasibility of this method. In order to achieve pressurization of the 2-3/4 ton unit, the tank (see Figure 10) was initially filled with 4076 lbs of HALON 1301 by means of a 5-gpm pump.

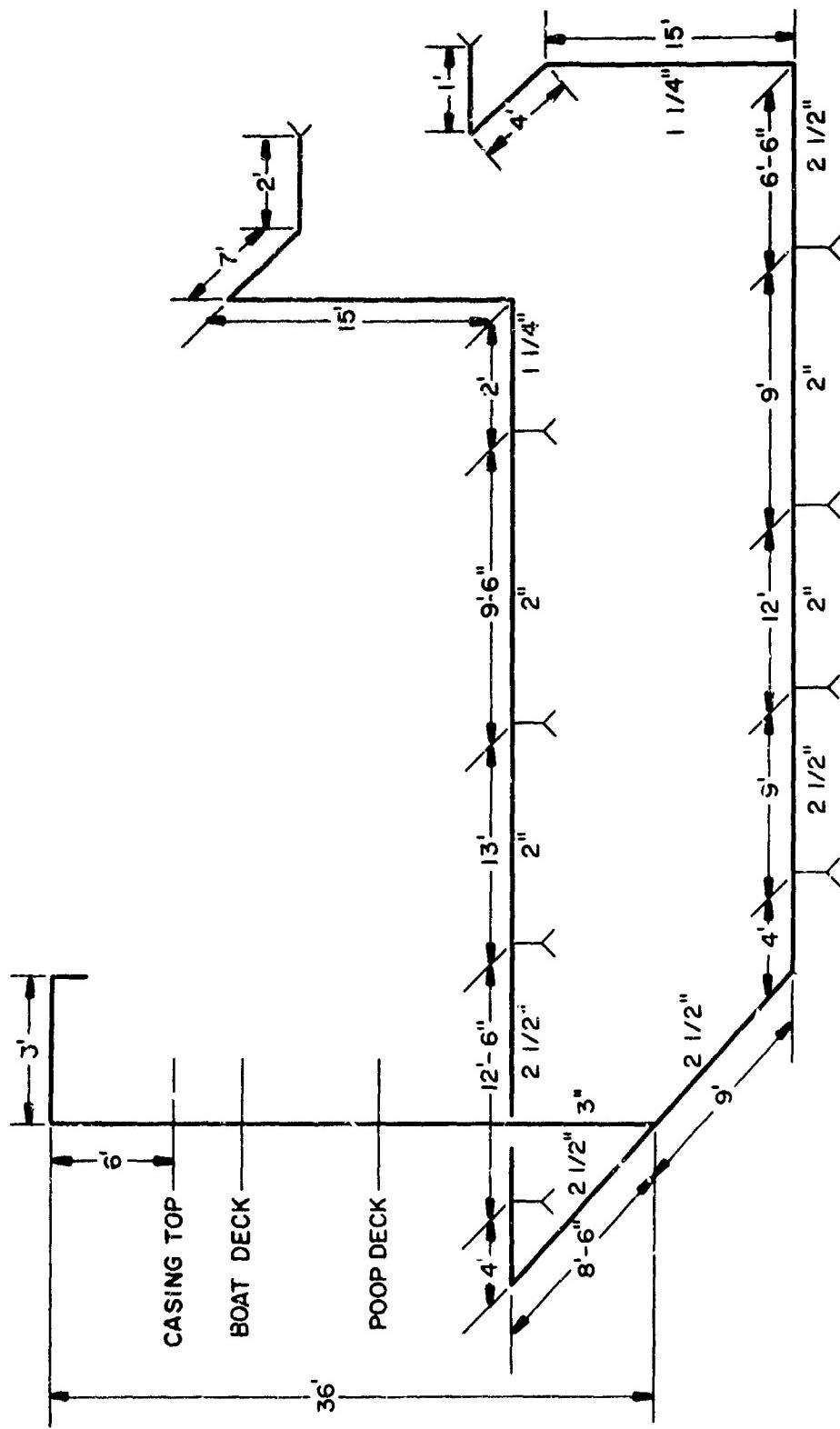
The HALON 1301 was then recirculated through a 1500-watt external heater, which was found to be inadequate to raise the pressure to the desired level. Additional heat was provided by heating the transfer piping with a blow torch. The heater's effectiveness was limited by the fact that electricity was only available during daylight hours. If it had been possible to run the heater continuously, the heater alone would have been sufficient.

System Problem. The HALON 1301 was manually released through a pneumatic pilot valve. Initially, difficulty was encountered in calculating the amount of HALON 1301 inside the tank, complicated by an approximate 3° list of the ship. This problem was overcome by blocking the tank until it was level to compensate for the list and then connecting a transparent plastic tube between the tank bottom auxiliary outlet and the tank top vapor outlet connection. When these changes were accomplished, the liquid level was then accurately measured.

INSTRUMENTATION

The responsibility for test instrumentation was divided as follows:

- National Bureau of Standards—
 - Temperature
 - Carbon monoxide and carbon dioxide levels
 - Oxygen levels



ALL PIPE SCHEDULE 80
NOZZLE STUBS 1" x 1/4"

FIGURE 9. HEATED LOW PRESSURE SYSTEM DIAGRAM.

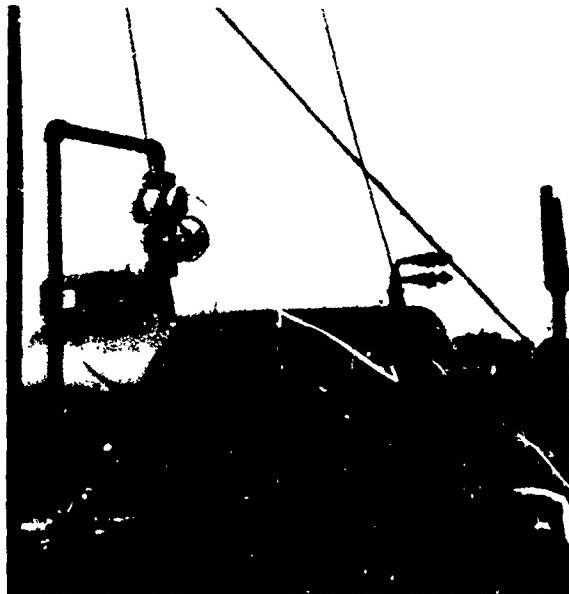


FIGURE 10. HEATED LOW PRESSURE SYSTEM TANK.

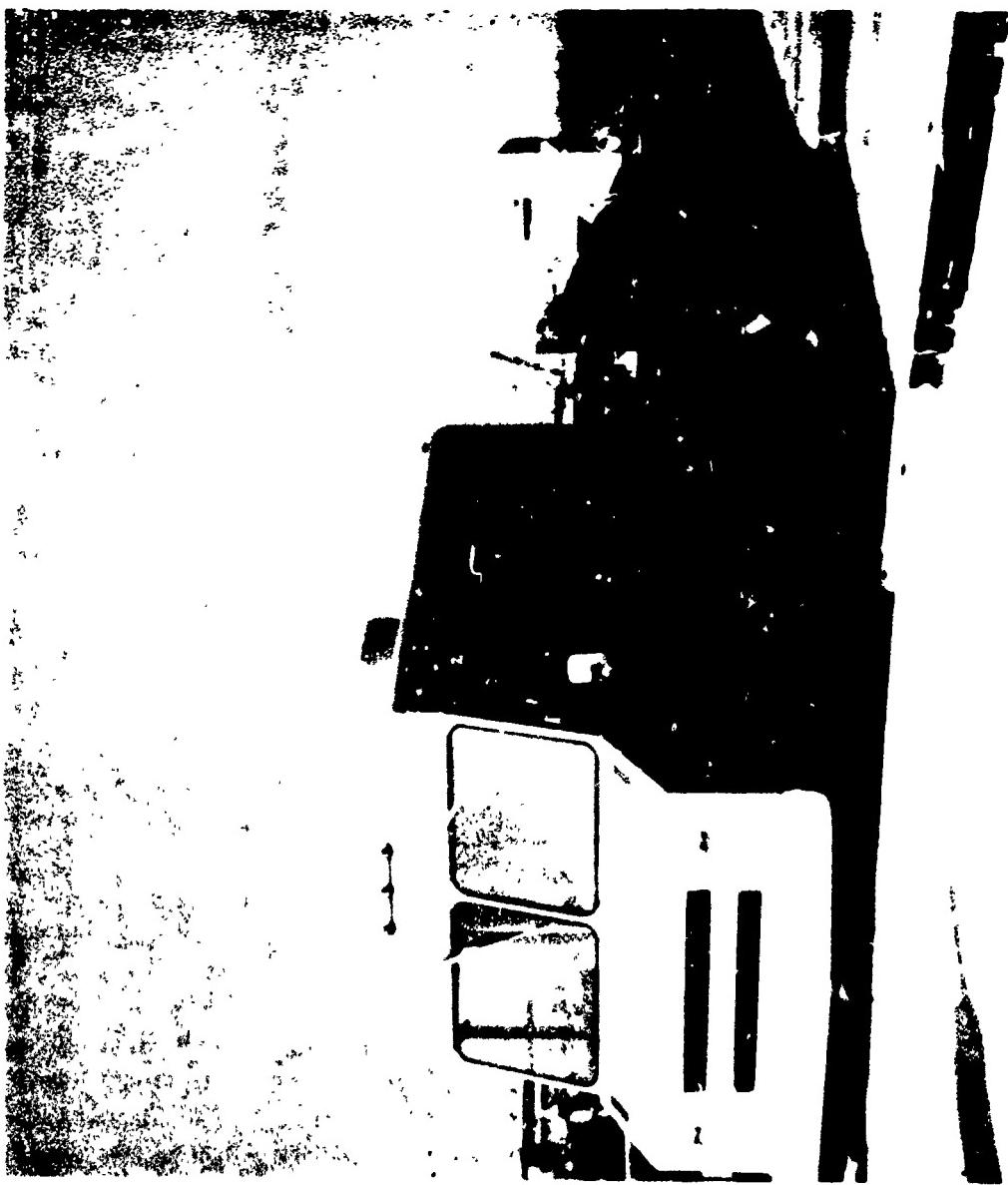
- E. I. Dupont De Nemours and Company—
HALON 1301 concentrations
HF and HB_F concentrations
- The Cardox Corporation—
HALON 1301 concentrations

NATIONAL BUREAU OF STANDARDS. The National Bureau of Standards mobile fire research van, shown in Figure 11, contained instrumentation designed to continuously monitor temperature, carbon monoxide, and carbon dioxide levels throughout the machinery space of the M/V RHODE ISLAND. Rapid response thermocouples were installed in the grid pattern illustrated in Figures 3 and 4. Table 1 details the exact location of the thermocouples. The temperatures were recorded on a 24-point cycle recorder and on a punch tape data logger.

Carbon monoxide, carbon dioxide, and oxygen were recorded on the data loggers and were measured by an MSA fire gas analyzer, Model No. 300. Sampling point locations are identified in Figures 3 and 4.

DUPONT. The apparatus and methods utilized to measure concentrations of Halon 1301, hydrogen bromide, hydrogen fluoride, and carbon dioxide are completely described in DuPont Reports KSS-7105 (7) and KSS-7105A. (8) Basically, the methods utilized evacuated cylinders which, when electrically operated, sampled the atmosphere. After taking atmosphere samples, the cylinders were removed and their contents chemically analyzed.

FIGURE 11. NATIONAL BUREAU OF STANDARDS MOBILE FIRE RESEARCH VAN.



During the "no fire" agent distribution test, (test 0) portable Gow Mac meters were utilized to measure the HALON 1301 concentrations.

CARDOX. During fire tests 5 and 6, concentrations of HALON 1301 were recorded on a continuous strip recorder. The recorder appears to have several advantages over the meter readout Gow Mac meter which does not provide a permanent record of the data.

DATA COLLECTION

The Ansul Company was responsible for recording discharge times and weights of HALON 1301 used for their equipment.

NFPA 12A (4) defines discharge time as the time interval between appearance of HALON 1301 liquid at the nozzle and the reappearance of vapor. There are several methods by which this can be measured, the most common of which is the audio method. In the audio method, the time between liquid and vapor at the nozzle is characterized by a high shrill sound. When liquid appears, there is a definite lowering of the sound pitch. This pitch increases when the vapor reappears for the last remaining pounds of HALON 1301 in a tank. During the "no fire" agent distribution test, (test 0) a pressure gage was placed at the tank top. The pressure drop was filmed during this test, and the data is presented in the description of this test in Chapter III.

TABLE 1. THERMOCOUPLE LOCATIONS.

Thermo-couple No.	Side of Ship	Distance From CL	Frame No.	Height Above Deck	Air or Metal	Location
1	CL	0	42	8'	Air	
2	Stbd	8'	42	8'	Air	
3	Stbd	17'	42	0	Metal	Deck Plate
4	Stbd	8'	36	8'	Metal	Engine
5	Stbd	16'	36	8'	Air	
6	Stbd	8'	32	8'	Air	
7	Stbd	8'	28	8'	Metal	Beam
8	Stbd	8'	24	8'	Air	
9	CL	0	20	8'	Air	
10	CL	0	10	8'	Air	
11	Port	8'	24	8'	Air	
12	Port	8'	28	8'	Metal	Grate
13	Port	8'	32	8'	Air	
14	Port	8'	36	8'	Air	
15	Port	16'	36	8'	Metal	Column
16	Port	8'	42	8'	Air	
17*	Port	17'/8'	42	0	Metal	Deck Plate
18	CL	0	42	3'	Metal	Engine
19	CL	0	44	4'	Metal	Fuel Oil Burner
20	Port	20	42	20'	Metal	Water Tank

TABLE 1. THERMOCOUPLE LOCATIONS. (Continued)

Thermo-couple No.	Side of Ship	Distance From CL	Frame No.	Height Above Deck	Air or Metal	Location
21	Stbd	8'	32	20'	Air/Metal	CO ₂ Pipe
22	Port	8'	32	15'	Metal	Grate
23	CL	0	32	46'	Air	Skylight
24	Port	12	30	30'	Air	Companionway

* #17 relocated @8' port after Ansul #2

Chapter III

TEST RESULTS

GENERAL DATA

The HALON 1301 tests using CBrF₃ as the extinguishing agent are described in table 2, which presents a brief summary of pertinent data.

TABLE 2. BRIEF DATA SUMMARY.

Test No.	Date	Preburn Length (min)	Design Conc. HALON 1301 (%)	Duration of Discharge (sec)
<u>Ansul</u>				
0	Nov. 11, 1970	No fire	5.65	10.9
1	Nov. 12, 1970	10	5.65	10
2	Nov. 13, 1970	10	4.40	7
3	Nov. 14, 1970	1	4.40	7
4	Nov. 14, 1970	20	5.65	10
<u>Cardox</u>				
5	Nov. 19, 1970	1	3.39	18
6	Nov. 19, 1970	10	4.46	28

DETAILED DATA

Table 3 presents a detailed summary of test data obtained during the program.

In order to describe all phases of the test program the following format will be utilized:

- Date
- Length of Preburn
- Discharge Time
- Agent Concentration
- Test Objectives
- Environmental Conditions (Wind direction indicated from its direction of origin)
- Test Sequence
- Measurement of HALON 1301 Products of Decomposition
- Temperature Observations
- Analysis
- Conclusions
- Figures
 - Measurement of HALON 1301 Products of Decomposition
 - Temperature Charts

TABLE 3. D

Item	Agent Distribution Test 0 (No Fire)	Fire Test 1	Fire Test 2	Fire Test 3
Date	11-11-70	11-12-70	11-13-70	11-14-70
Time	9:30 AM	1:30 PM	10:00 AM	9:00 AM
Preburn Time	N/A	10 min	10 min	1 min
Spray Fuel Fire	N/A	Yes	Yes	--
Calculated HALON 1301 Concentration	5.65%	5.65%	4.4%	4.4%
Weight of HALON 1301	2340 lbs	2340 lbs	1800 lbs	1800 lbs
Nitrogen Superpressure	580 psig @64°F	530 psig @49°F	530 psig @49°F	570 psig @62°
Calculated Discharge Time	7.5 sec	7.5 sec	4.7 sec	4.7 sec
Actual Discharge Time*	10.9 sec	10 sec	7 sec	7 sec
Max. Air Temperature		511°C	666°C	60°C
Max. Metal Temperature		351°C	280°C	115°C
Vents Closed	Entire test	Before discharge	Before discharge	At discharge
Fan Off	Entire test	Before discharge	Before discharge	At discharge
HALON 1301 Concentration				
Deck 1	10.9%			
Deck 2	6.3 - 6.4%			
Deck 3	4.8 - 6.0%			
Deck 4	3.8 - 6.1%	8.0%	6.4%	3.5%
Deck 5	2.0 - 3.5%	6.7%	6.4%	3.1%
Companionway	—	3.0%	0.1%	2.3%
HF Concentration				
Deck 4	—	2.2 - 2.7 ppm	2.7 - 4.2 ppm	5.1 - 12 ppm
Deck 5	—	3.5 ppm	2.7 ppm	9.6 ppm
Companionway	—	1.0 ppm	0.4 ppm	0.6 ppm
HBr Concentration				
Deck 4	—	0.5 - 0.6 ppm	0.9 - 1.6 ppm	0.9 ppm
Deck 5	—	0.9 ppm	1.1 ppm	2.6 ppm
Companionway	—	0.4 ppm	0.4 ppm	0.3 ppm

*All times are approximate.

TABLE 3. DETAILED TEST DATA SUMMARY

Fire Test 1	Fire Test 2	Fire Test 3	Fire Test 4	Fire Test 5	Fire Test 6
11-12-70 1:30 PM 10 min Yes	11-13-70 10:00 AM 10 min Yes	11-14-70 9:00 AM 1 min —	11-14-70 1:15 PM 20 min —	1-19-70 10:30 AM 1 min	11-19-70 1:00 PM 10 min
5.65% 2340 lbs 530 psig @49°F 7.5 sec 10 sec 511°C 351°C Before discharge	4.4% 1800 lbs 530 psig @49°F 4.7 sec 7 sec 656°C 280°C Before discharge	4.4% 1800 lbs 570 psig @62°F 4.7 sec 7 sec 60°C 115°C At discharge	5.65% 2340 lbs 560 psig @59.5% 7.5 sec 10 sec ≥1200°C 800°C All but one at discharge	3.39% 1371 lbs 45°C 76°C At discharge	4.64% 1903 lbs 28 sec 1014°C At discharge
8.0% 6.7% 3.0%	6.4% 6.4% 0.1%	3.5% 3.1% 2.3%	6.4% 0.1% 12.7%		
2.2 - 2.7 ppm 3.5 ppm 1.0 ppm	2.7 - 4.2 ppm 2.7 ppm 0.4 ppm	5.1 - 12 ppm 9.6 ppm 0.6 ppm	—ppm —ppm	0.1 ppm —	230 ppm —
0.5 - 0.6 ppm 0.9 ppm 0.4 ppm	0.9 - 1.6 ppm 1.1 ppm 0.4 ppm	0.9 ppm 2.6 ppm 0.3 ppm	—ppm —ppm —ppm	0.6 ppm — —	68 ppm — —

B

TEST NO. 0

DATE: November 11, 1970

LENGTH OF PREBURN: No fire

DISCHARGE TIME: 10.9 seconds

AGENT CONCENTRATION: 5.65 percent. 2340 lbs of HALON 1301

TEST OBJECTIVES:

1. Determine whether discharge time could be achieved.
2. Determine if agent distribution could be achieved.
3. Uncover any system flaws.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 60°F

Humidity: 65 percent

Wind Direction and Speed: W, 7 knots

Barometric Pressure: 29.80 in Hg

Ventilation:

1. Skylights closed.
2. Ventilation closed.
3. All other openings secured
4. Bottom half of dutch door (2' x 3') leading to engine room from adjacent companionway open.

TEST SEQUENCE:

1. Tank charged with 2340 lbs of HALON 1301.
2. Pressure tops and gages placed on the nozzles.
3. Pressure gage placed on the tank.
4. Agent discharged.
5. Tank pressure drops recorded.
6. Agent concentration and uniformity measured.

ANALYSIS AND OBSERVATIONS:

The design discharge time of 7.5 seconds for the HALON 1301 was not obtained during the test. Agent discharge actually required 10.9 seconds, and in addition, the entire set of nozzles was replaced with larger orifice nozzles.

The concentration of HALON 1301 was not uniform in all levels of the machinery space, i.e., a higher concentration was achieved in the bilge area. The distribution is detailed in Table 4.

TABLE 4. HALON 1301 AGENT DISTRIBUTION TEST (NO FIRE)

Deck Levels	HALON 1301 Concentrations, Volume Percent		
	Gow Mac #1	Gow Mac #2	Evacuated Bottle
5	10.9	—	0.4
4	6.4	6.3	—
3	4.8	6.0	—
2	4.0	3.8	6.1
1	2.0	—	3.5

Concentration measurements were taken over a period of approximately 5 minutes. The marked difference in concentration at the top of the machinery space can partially be explained because of the open dutch door. Subsequent examination of the space revealed other minor openings, including an 8" x 12" opening in an exhaust vent. This vent led from the engine room to a companionway on the port side of the vessel. The difference in concentration can further be explained by the fact that the intended design concentration was calculated on a gross area of 100,000 ft³ and did not account for any machinery in the space. The bulk of the machinery is in the bilge area and, therefore, would tend to increase the concentration in this area. The disparity between the Gow Mac thermal conductivity meters and the evacuated bottle for the bilge area cannot be explained. Dupont report KSS-7105 (7) theorizes that the bilge area disparity was due to a leaky solenoid valve.

Prior to system discharge, the piping had been blown down with air to dislodge any foreign material and to ensure piping soundness. After the HALON 1301 was discharged through the system, two chill rings (welding backing strips) were found at a nozzle orifice. It is speculated that the force of the liquid HALON 1301 may have been sufficient to cause the chill rings to break loose.

Figure 12 illustrates a graph of tank top pressure versus time. Tank top pressure is the adjusted pressure in the storage tank due to the displacement of HALON 1301 filling the pipe line. Figure 12 was derived from a photographic record of the tank top pressure as measured by a gauge. The photographic record indicated that the actual discharge time was 10.9 seconds. This discharge time confirmed that extrapolation of currently available friction loss figures is possible for larger-size piping.

CONCLUSIONS:

1. Spaces such as the tested machinery space should be tightly sealed to prevent agent loss.
2. Known ventilation losses should be compensated for in system design for design application.
3. A discharge test is recommended to determine uniformity of agent distribution.
4. If a fire occurred at the upper level of the engine room, from a day tank or other flammable liquid tank, it is unlikely that the fire would be extinguished if a concentration reversal occurred; however, a concentration reversal is unlikely.
5. Extrapolation of currently available friction loss data for small piping can be accomplished for larger sized piping.

TANK PRESSURE VS. TIME

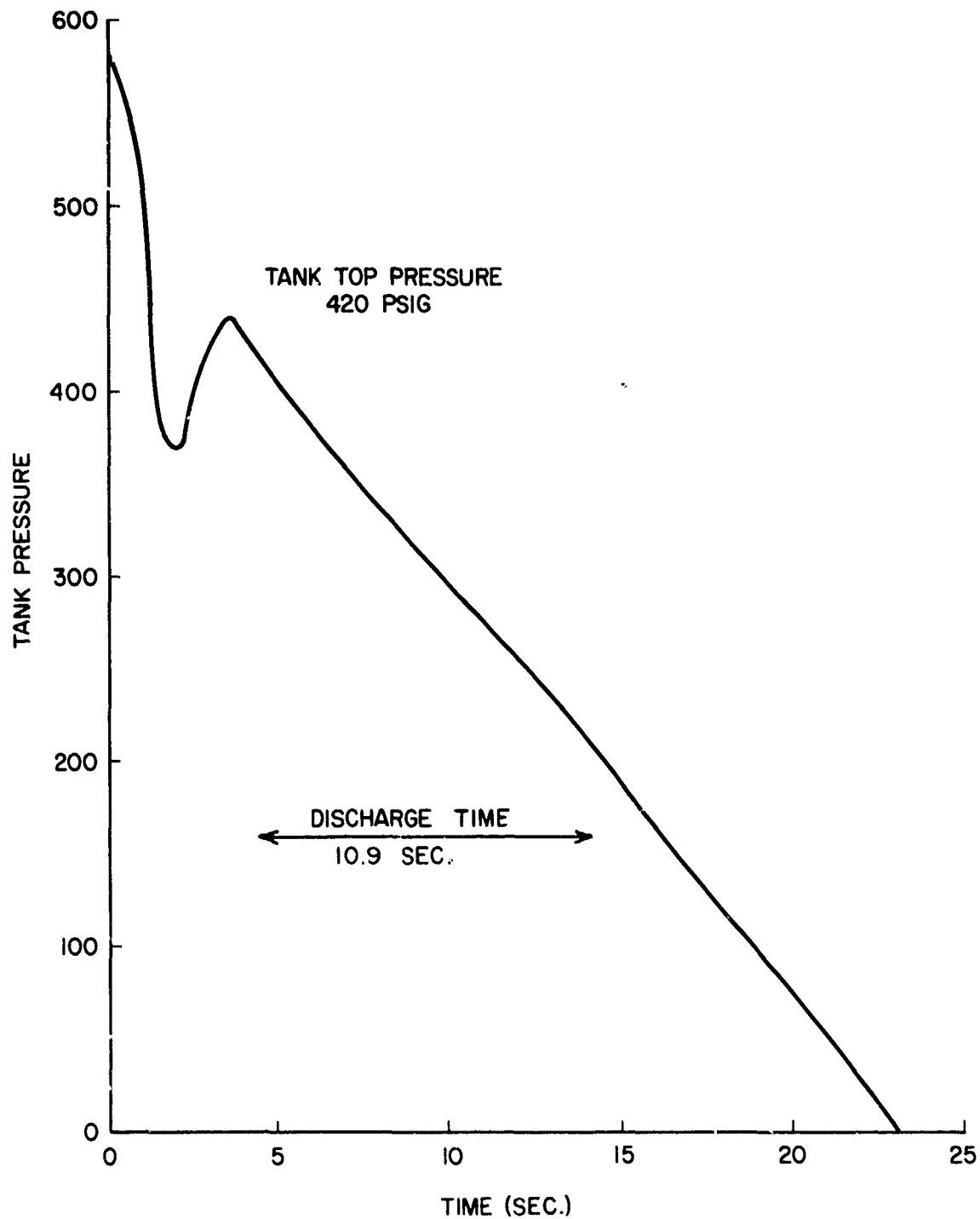


FIGURE 12. DISCHARGE TIME VS. TANK PRESSURE.

TEST NO. 1

DATE: November 12, 1970

LENGTH OF PREBURN: 10 minutes

DISCHARGE TIME: 10 seconds

AGENT CONCENTRATION: 5.65% (2340 lbs. of HALON 1301)

TEST OBJECTIVES:

1. Simulate an engine room bilge fire.
2. Apply HALON 1301 in a 5.65-percent concentration to determine effectiveness in extinguishing a fire of this type.
3. Measure concentrations of HALON 1301, hydrogen fluoride, hydrogen bromide, carbon monoxide, carbon dioxide, and oxygen.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 65°F

Humidity: 57 percent

Wind Direction and Speed: NW, 11 knots

Barometric Pressure: 29.64 in Hg

Ventilation:

1. Skylights closed

2. Main ventilators open (6)

3. Two 37,500-cfm fans operating until 1 minute before discharge.

TEST SEQUENCE:

1. Primed marine diesel ignited (four ignition points).
2. Clock started with visual confirmation of ignition.
3. Two intake fans started immediately after confirmation of ignition.
4. Carbon monoxide, carbon dioxide, oxygen concentrations, and temperature continuously monitored.
5. Fans secured and air vents covered 1 minute before discharge.
6. Fuel spray started 1 minute before discharge and continued until 1 minute after discharge.

7. HALON 1301 discharged at 10-minute mark.
8. Samples of HALON 1301, oxygen, and carbon monoxide concentrations taken 40 seconds after discharge.
9. Samples of HF and HBr concentrations taken 50 seconds after discharge.
10. Determined whether or not fire was successfully extinguished.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION

As indicated in the test sequence, sampling was made shortly after discharge for the concentrations of HF, HBr, and CB_rF₃. Sampling results are shown in Figure 13. The highest concentration of HF was 3.5 ppm and the highest concentration of HBr was 0.9 ppm. Figure 13 also shows the locations of the samplers in the companionway and on the bulkheads. Sampler locations were unchanged during the test program.

Concentrations of oxygen and carbon dioxide were determined at the same time as the concentrations of HF and HBr. The oxygen level in the machinery space was 3-percent lower than in the companionway; however, the concentration of carbon dioxide was greater in the companionway (see Figure 14).

TEMPERATURE OBSERVATIONS:

Refer to Figures 15 through 18 for recorded temperature observations.

ANALYSIS:

1. Thermocouple readings suggest the test fire was primarily located in the machinery space forward portion. This location would indicate that during the 10-minute preburn, the fire did not spread aft rapidly; however, in the forward location the fire was intense.
2. Thermocouple temperatures in the vicinity of the fuel spray nozzles do not give positive proof of ignition.
3. Sufficient temperatures were developed to decompose the CB_rF₃.

CONCLUSIONS:

1. The test fire was successfully extinguished with a HALON 1301 concentration by volume of 5.65 percent.
2. Decomposition products of HALON 1301, hydrogen fluoride, and hydrogen bromide were present in limited quantities.

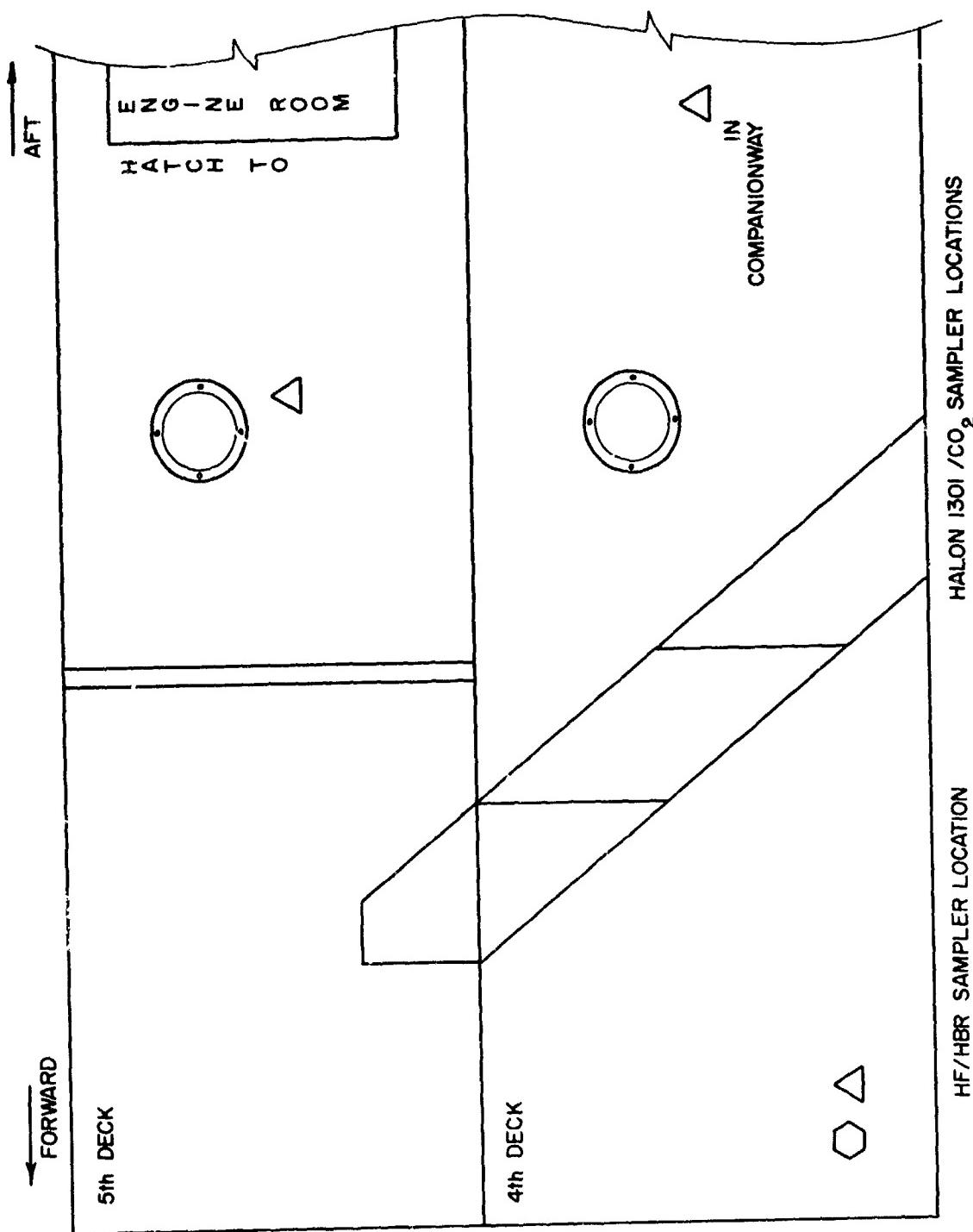


FIGURE 13. PRODUCTS OF DECOMPOSITION, TEST NO. 1 (Sheet 1 of 2).

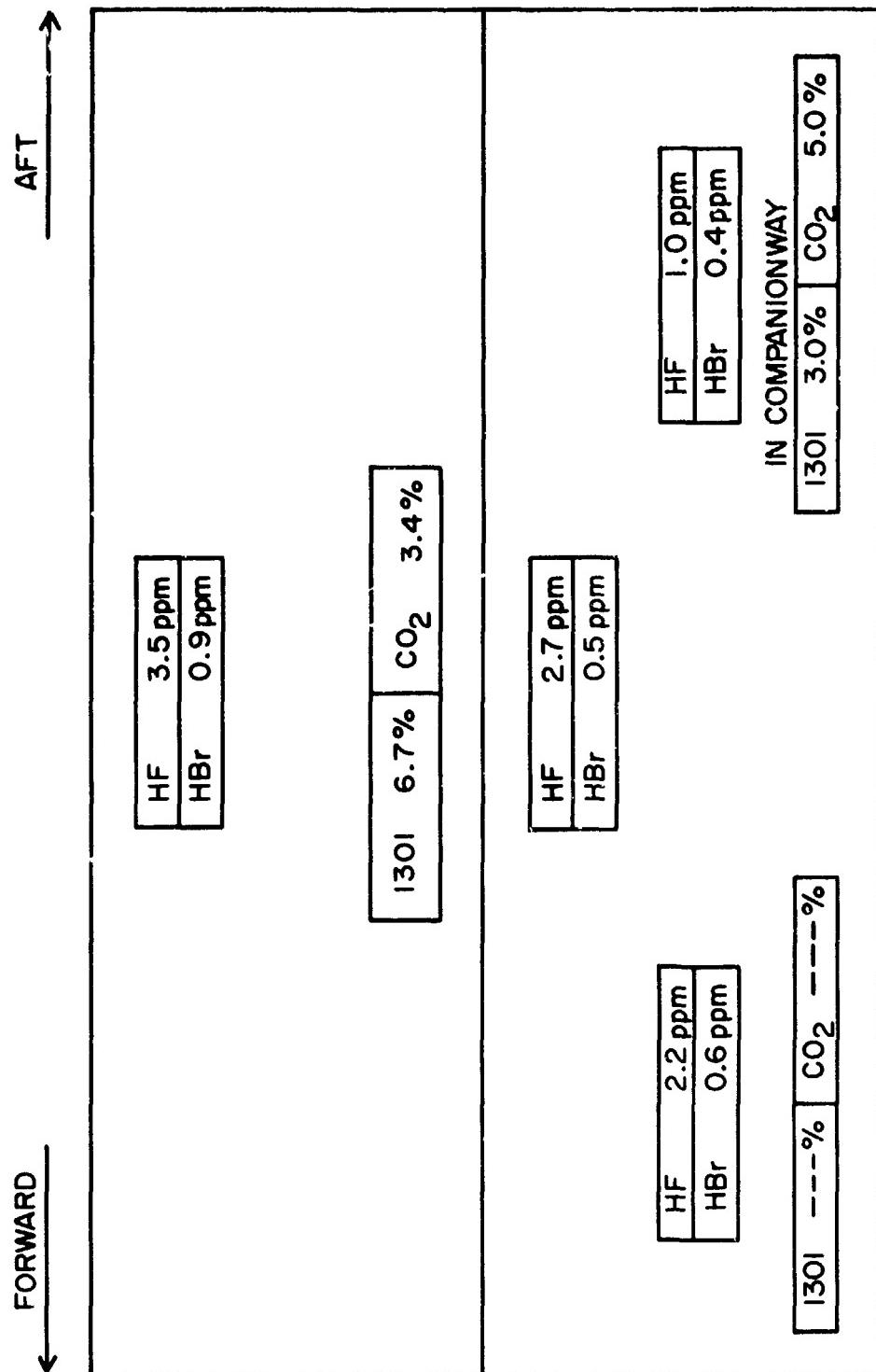


FIGURE 13. PRODUCTS OF DECOMPOSITION, TEST NO. 1 (Sheet 2 of 2).

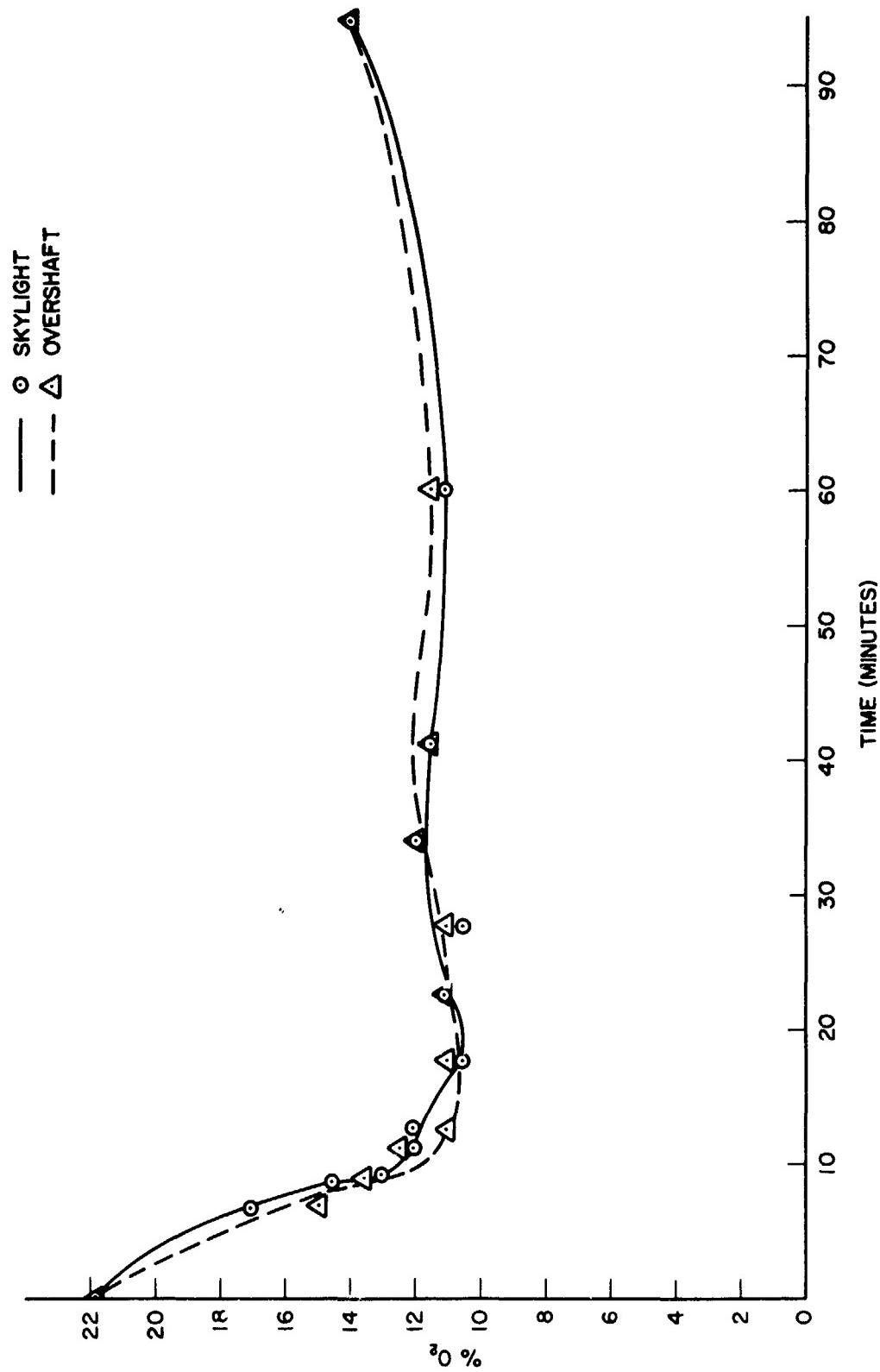


FIGURE 14. OXYGEN CONCENTRATION VS. TIME, TEST NO. 1.

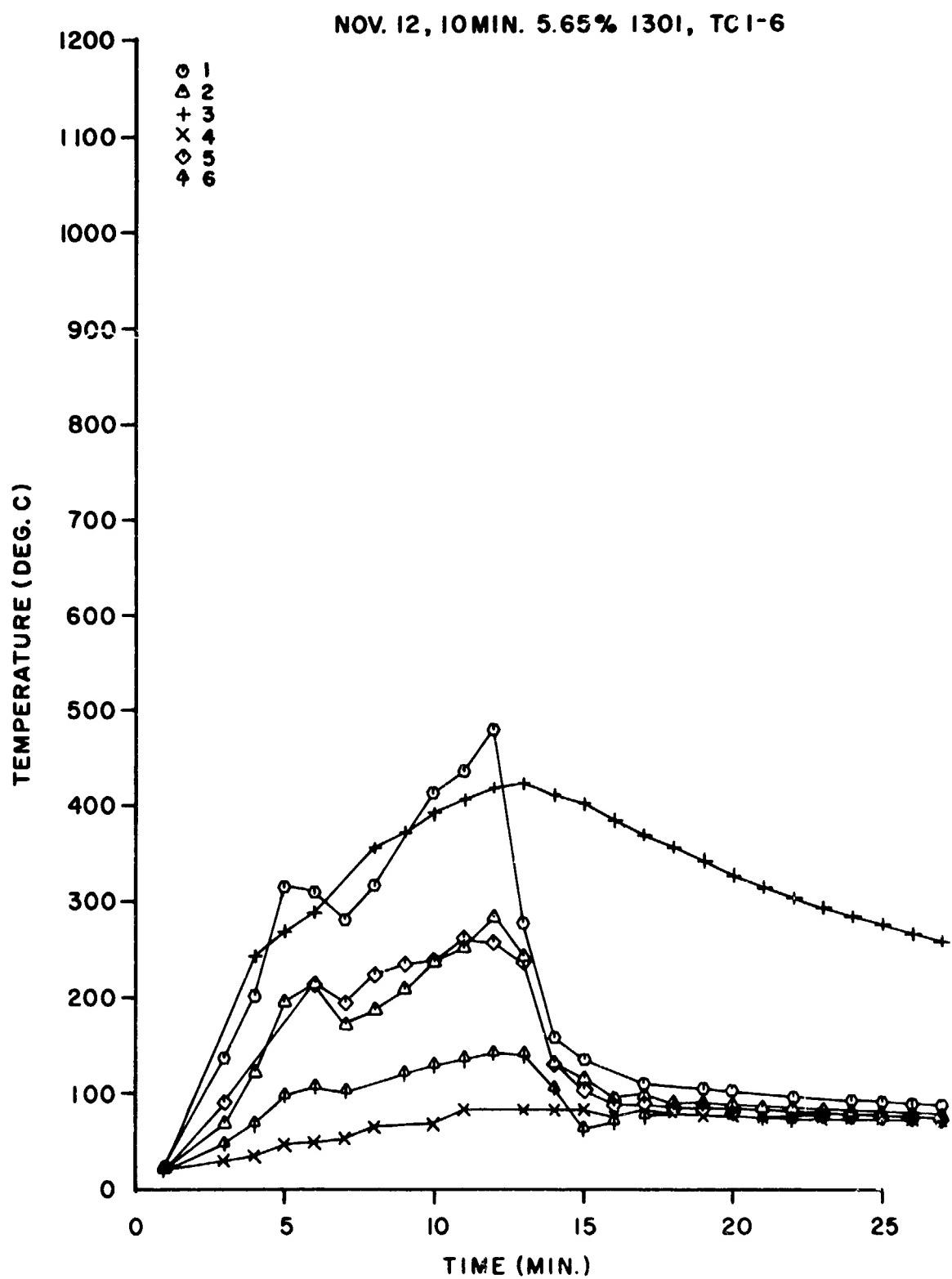


FIGURE 15. TEMPERATURES (TC 1-6), TEST NO. 1.

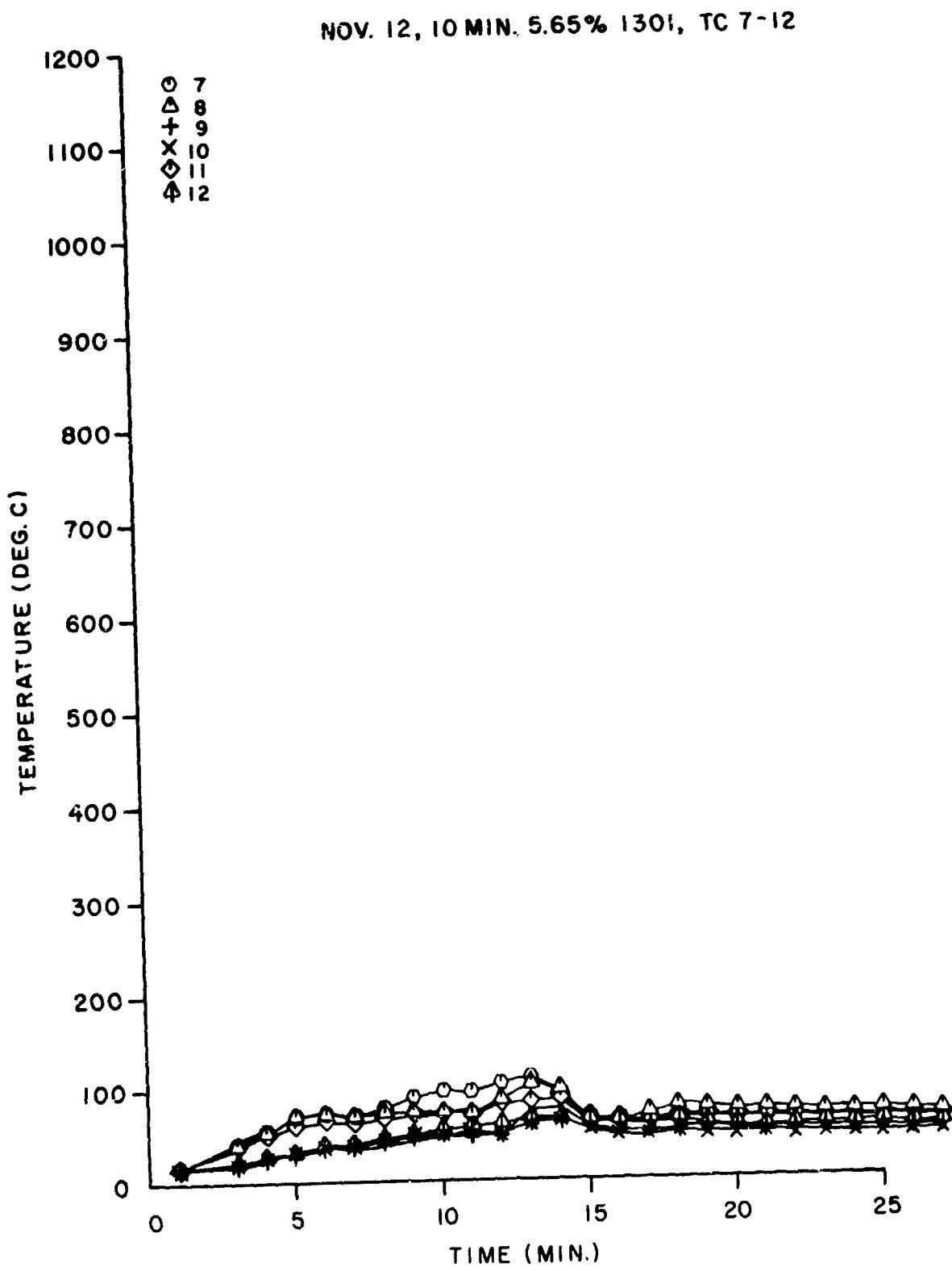


FIGURE 16. TEMPERATURES (TC 7-12), TEST NO. 1.

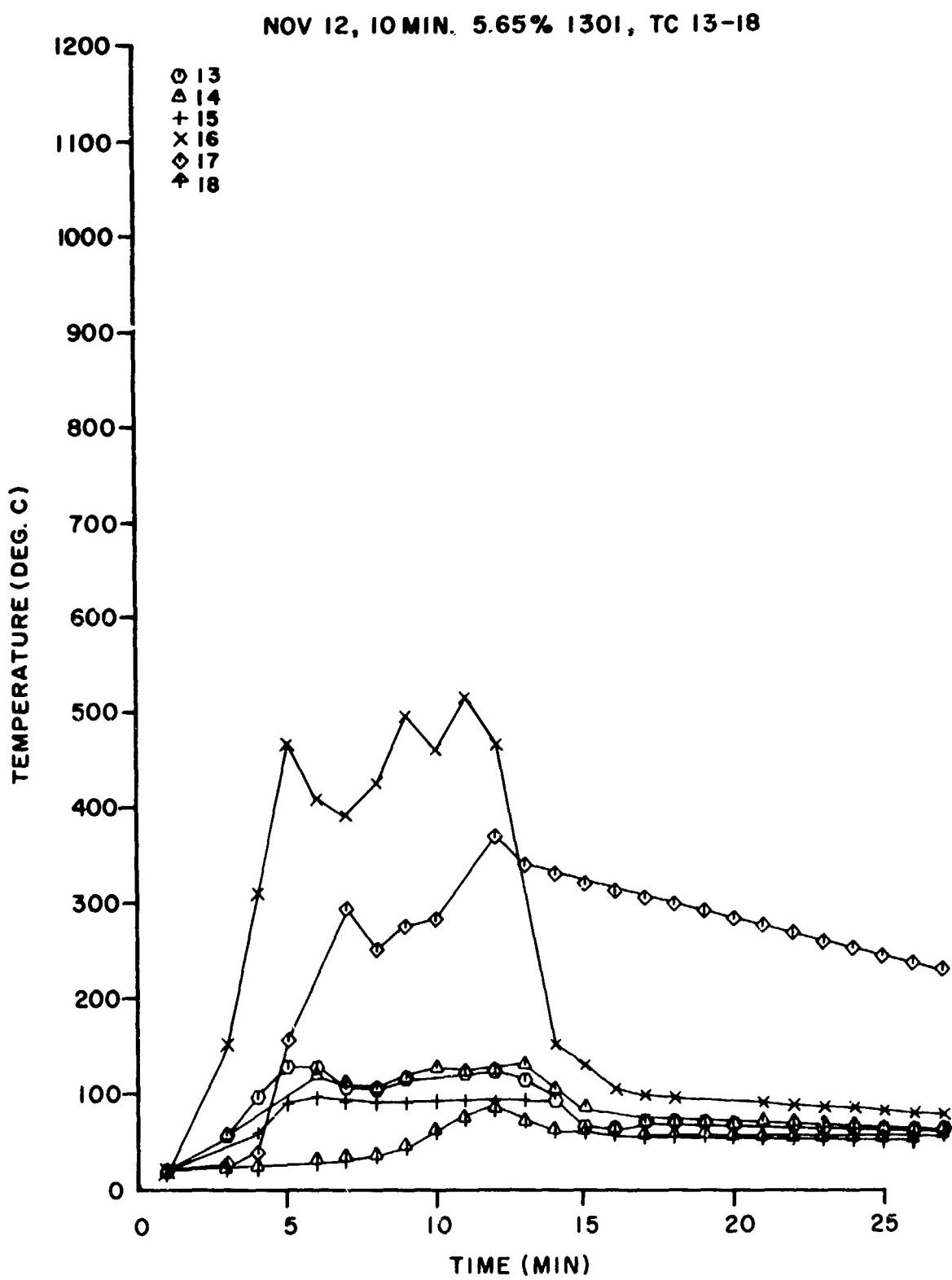


FIGURE 17. TEMPERATURES (TC 13-18), TEST NO. 1.

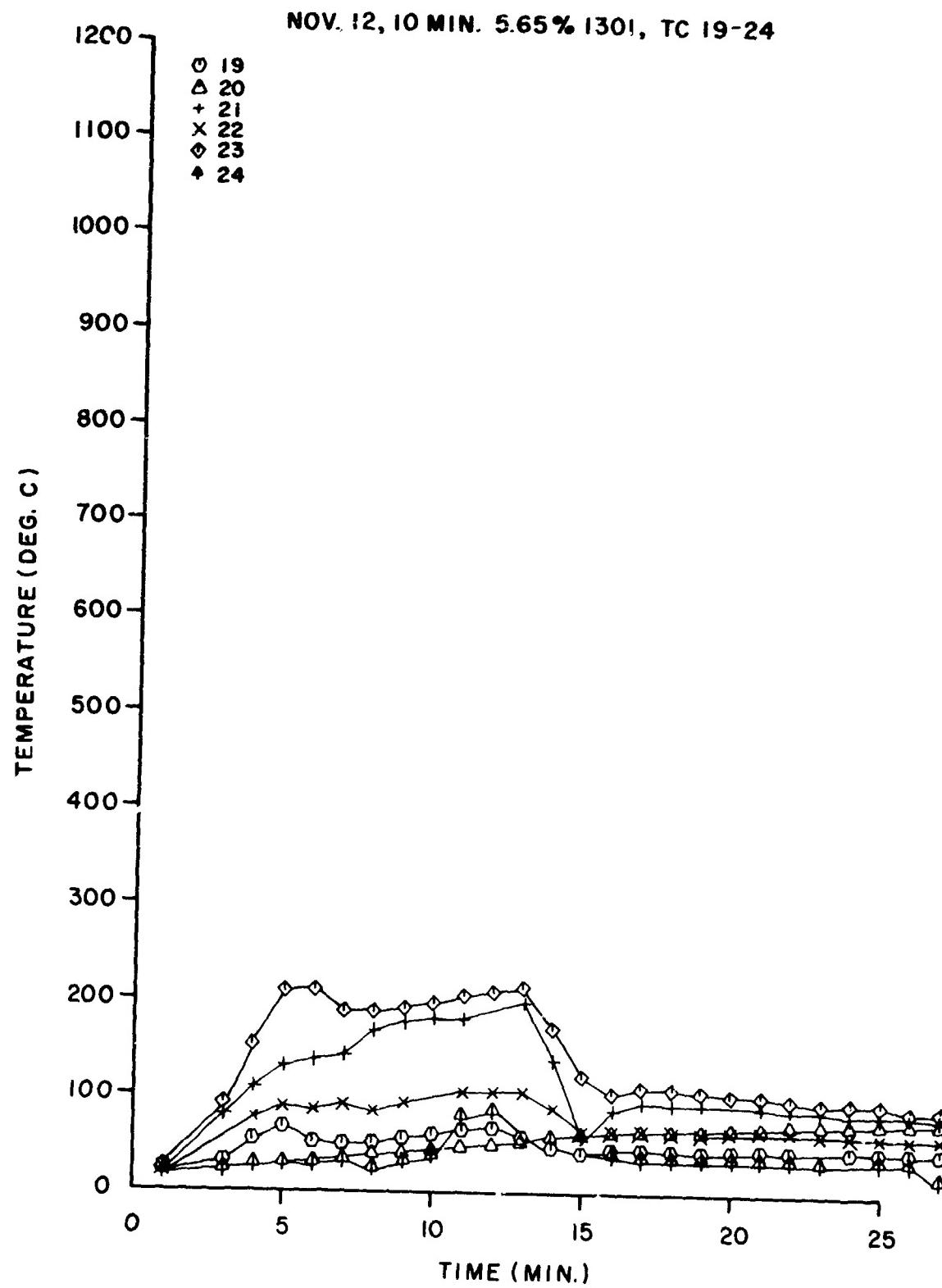


FIGURE 18. TEMPERATURES (TC 19-24), TEST NO. 1.

TEST NO. 2

DATE: November 13, 1970

LENGTH OF PREBURN: 10 minutes

DISCHARGE TIME: 7 seconds

AGENT CONCENTRATION: 4.40 percent, 1800 lbs of HALON 1301

TEST OBJECTIVES:

1. Simulate an engine room bilge fire.
2. Determine HALON 1301 effectiveness in an extinguishing concentration of 4.40 percent.
3. Measure concentrations of HALON 1301, hydrogen fluoride, hydrogen bromide, carbon monoxide, carbon dioxide, and oxygen.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 62°F

Humidity: 87 percent

Wind Direction and Speed: S, 4 knots

Barometric Pressure: 29.6 in Hg

Ventilation:

1. Skylights closed.
2. Main ventilators open (6).
3. Two 37,500-cfm fans operating until 1 minute before discharge.

TEST SEQUENCE:

1. Primed marine diesel ignited by flares.
2. Clock started with visual confirmation of ignition.
3. Two intake fans started immediately after confirmation of ignition.
4. Carbon monoxide and oxygen concentrations continuously monitored.
5. Air vents covered and fans secured 1 minute before discharge.
6. Fuel spray started 1 minute before discharge and continued until 1 minute after discharge.

7. Discharge agent at 10-minute mark.
8. Samples of HALON 1301, oxygen, and carbon monoxide concentrations taken 40 seconds after discharge termination.
9. Samples of HF and HBr concentrations taken 50 seconds after discharge termination.
10. Determination of whether or not fire successfully extinguished.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION:

Sampling was identical to sampling in Test No. 1, and sampling results are shown in Figure 19.

In the companionway, concentrations of HF and HBr were lower than in the machinery space. The HALON 1301 concentration was lower, while the carbon monoxide concentration was higher, in the companionway than in the previous tests. Oxygen concentrations are shown in Figure 20.

TEMPERATURE OBSERVATIONS:

Refer to Figures 21 through 24 for recorded temperature observations.

ANALYSIS:

1. It is doubtful that the spray fire actually occurred, although the fuel spray system was employed.
2. The toxic products of decomposition of HALON 1301 remained at a low level.

CONCLUSIONS:

A 4.40 percent concentration of HALON 1301 rapidly extinguished this fire.

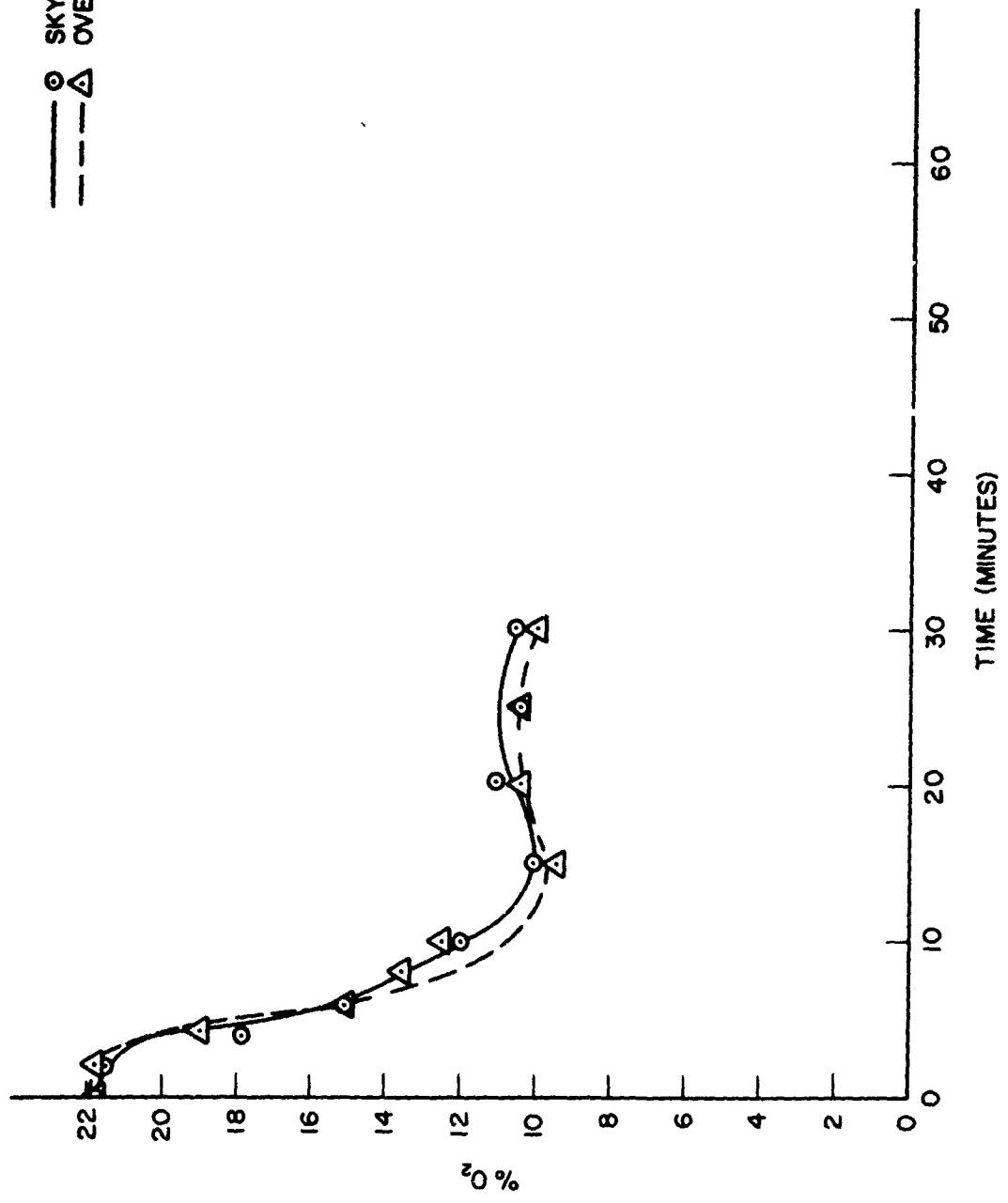
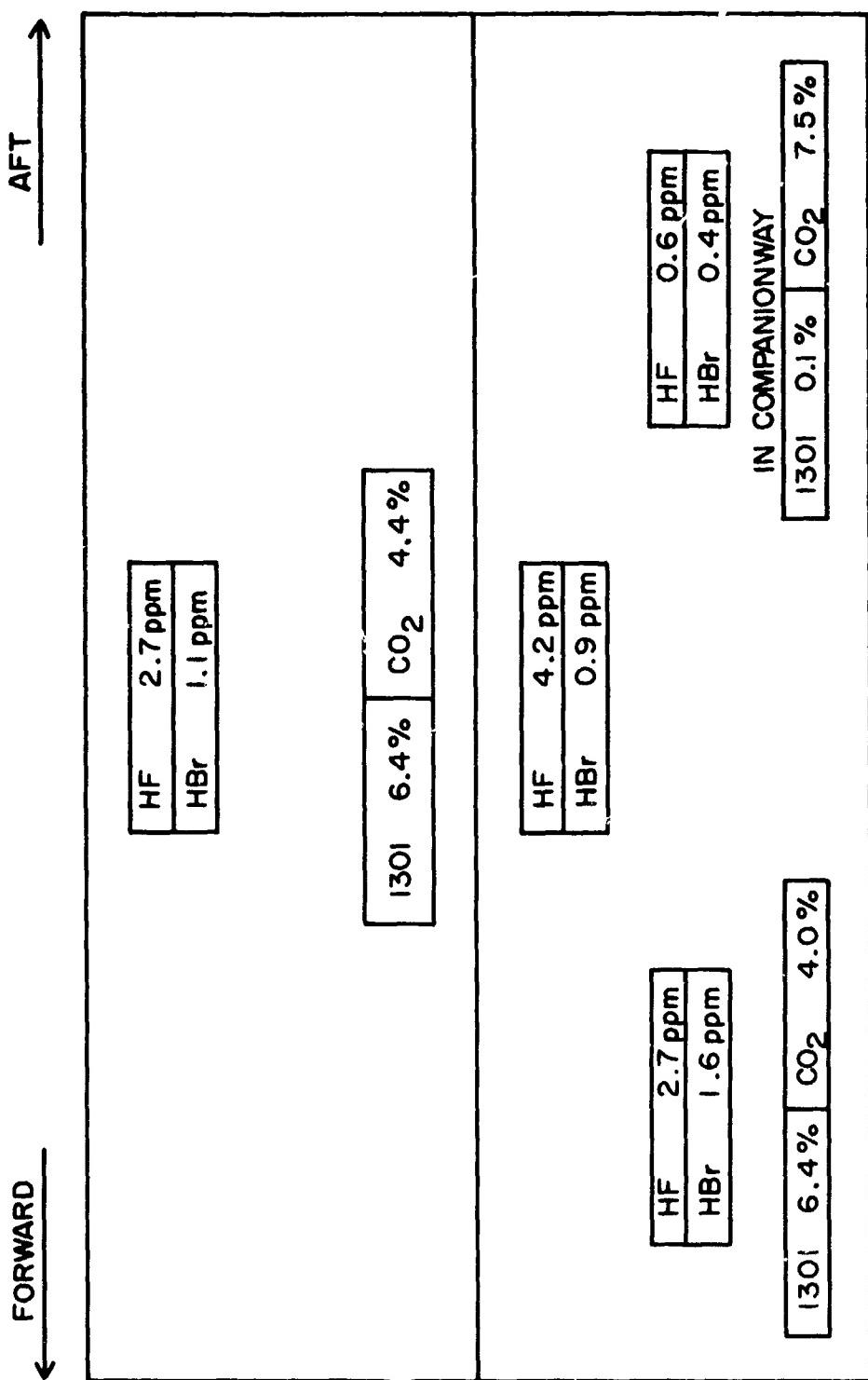


FIGURE 20. OXYGEN CONCENTRATIONS VS. TIME, TEST NO. 2.

FIGURE 19. PRODUCTS OF DECOMPOSITION, TEST NO. 2.



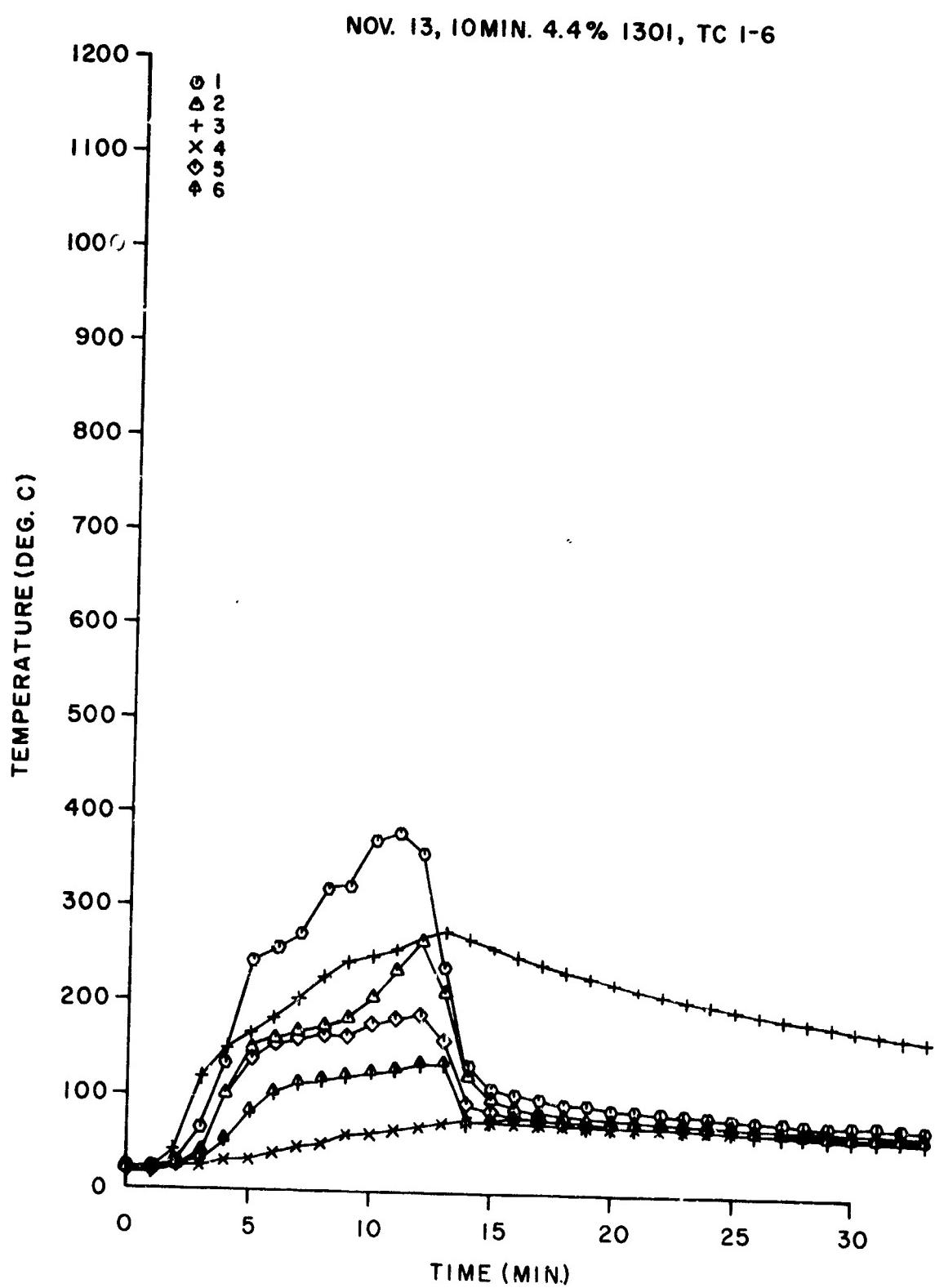


FIGURE 21. TEMPERATURES (TC 1-6), TEST NO. 2.

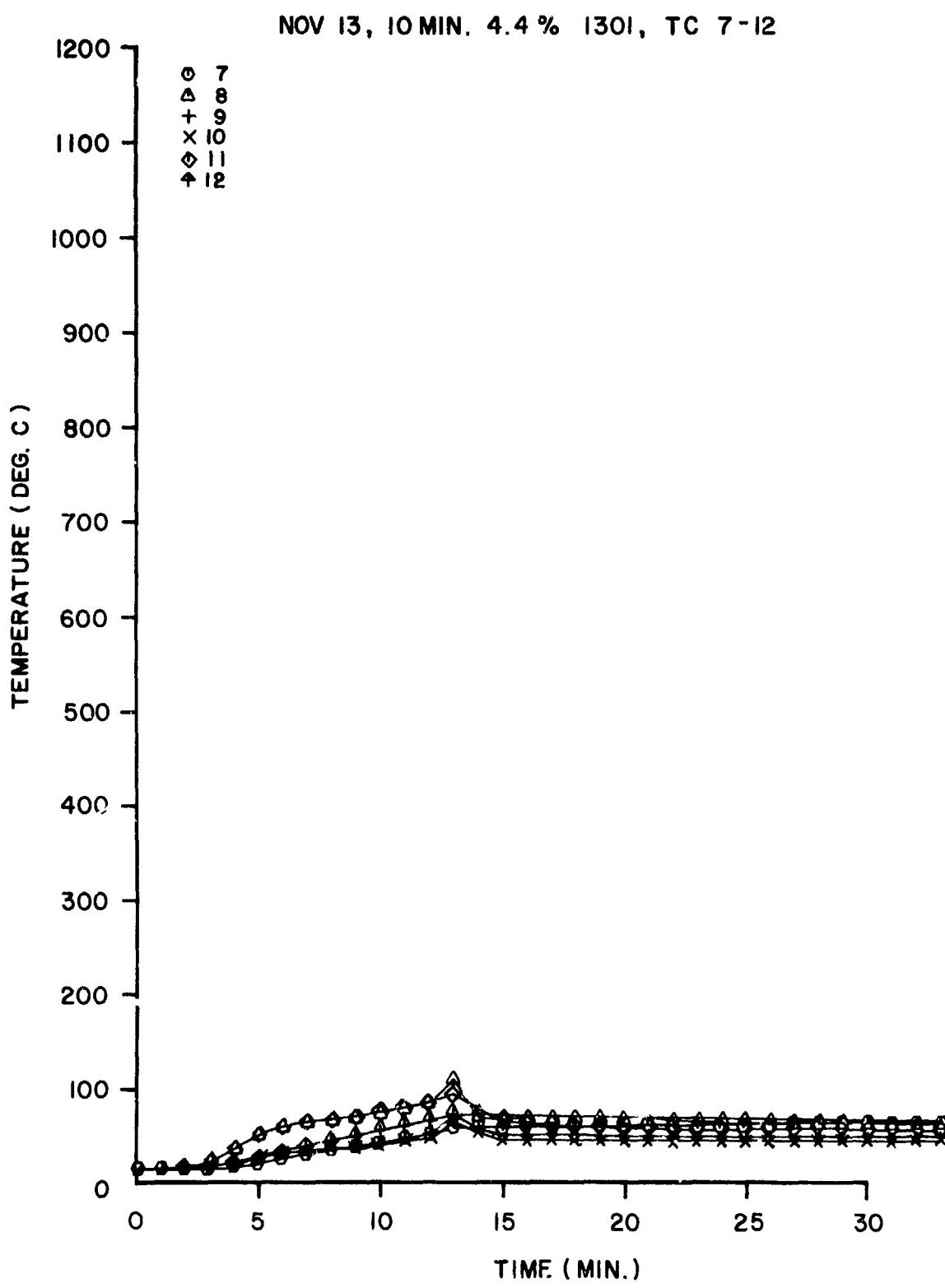


FIGURE 22. TEMPERATURES (TC 7-12), TEST NO. 2.

NOV. 13, 10 MIN. 4.4% 1301, TC 13-18

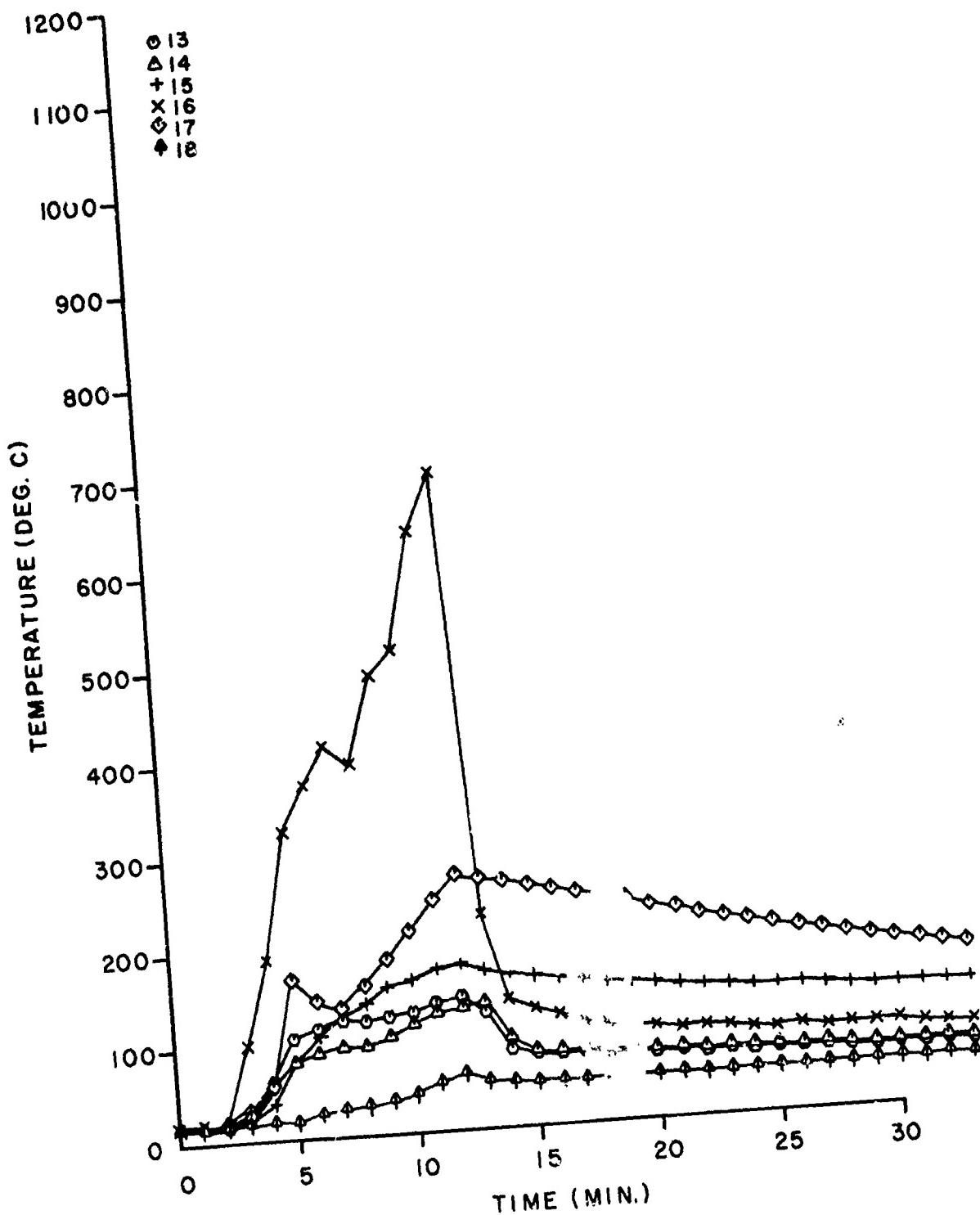


FIGURE 23. TEMPERATURES (TC 13-18), TEST NO. 2.

NOV 13, 10 MIN. 4.4% 1301, TC 19-24

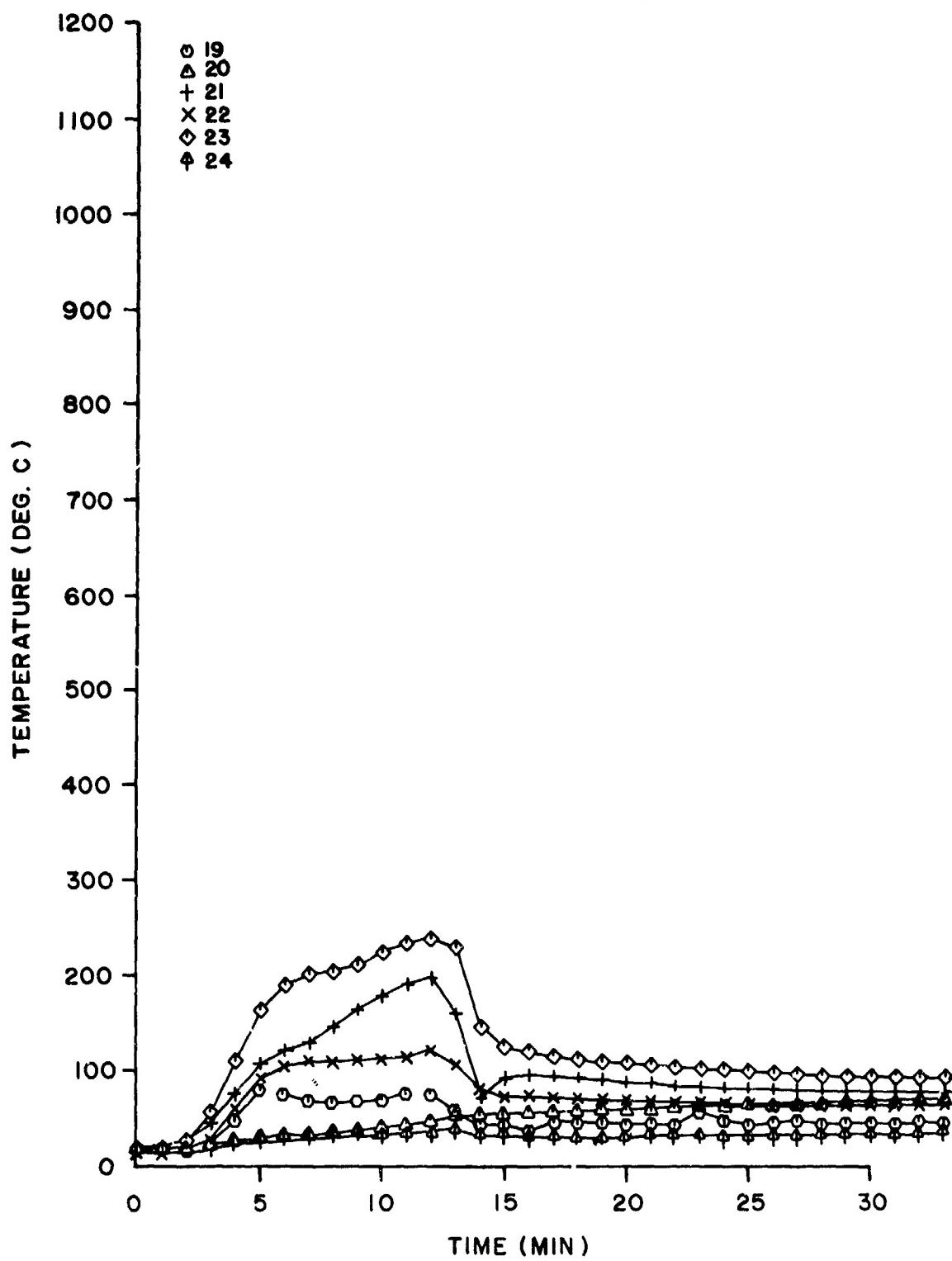


FIGURE 24. TEMPERATURES (TC 19-24), TEST NO. 2.

TEST NO. 3

DATE: November 14, 1970

LENGTH OF PREBURN: 1 minute

DISCHARGE TIME: 7 seconds

AGENT CONCENTRATION: 4.40 percent, 1800 lbs of HALON 1301

TEST OBJECTIVES:

1. Determine whether rapid detection with rapid discharge of HALON 1301 significantly reduce HALON 1301 decomposition products (effectiveness of this concentration verified in Test No. 2).
2. Simulate an engine room bilge fire.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 62°F

Humidity: 90 percent

Wind Direction and Speed: E, 4 knots

Barometric Pressure: 29.56 in Hg

Ventilation:

1. Skylights closed
2. Main ventilators open
3. Two 37,500-cfm fans operating until HALON 1301 is discharged.

TEST SEQUENCE:

1. Marine diesel fuel ignited (four ignitors, fuel was primed with 2 gallons of naptha).
2. Clock started with visual confirmation of ignition.
3. Intake fans started simultaneously with confirmation of ignition.
4. Fans shutdown and vents closed coincident with discharge of HALON 1301.
5. Samples of HALON 1301, oxygen, and carbon monoxide concentrations taken 40 seconds after discharge termination.
6. Samples of HF and HB_F concentrations taken 50 seconds after discharge termination.

7. Determination of whether or not fire was successfully extinguished.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION

Concentrations obtained are shown in Figure 25. The HF and HB_T concentrations are higher than concentrations obtained in the previous tests.

TEMPERATURE OBSERVATIONS:

Refer to Figures 26 through 29 for recorded temperature observations.

ANALYSIS:

1. This test fire was less severe than the other test fires.
2. Concentrations of HALON 1301 were lower than the design concentration, thus indicating escape or loss of the HALON 1301.
3. The HALON 1301 loss to the companionway in this test compares with the loss for the "no fire" test. The percentage difference between the design concentration and the concentration achieved in the companionway was 2.1 percent in both the "no fire" test and this test.

CONCLUSIONS:

1. The fire was successfully extinguished with a 4.4-percent concentration of HALON 1301.
2. Fires of the tested magnitude are best handled by other fire fighting equipment rather than utilizing a total flooding system.

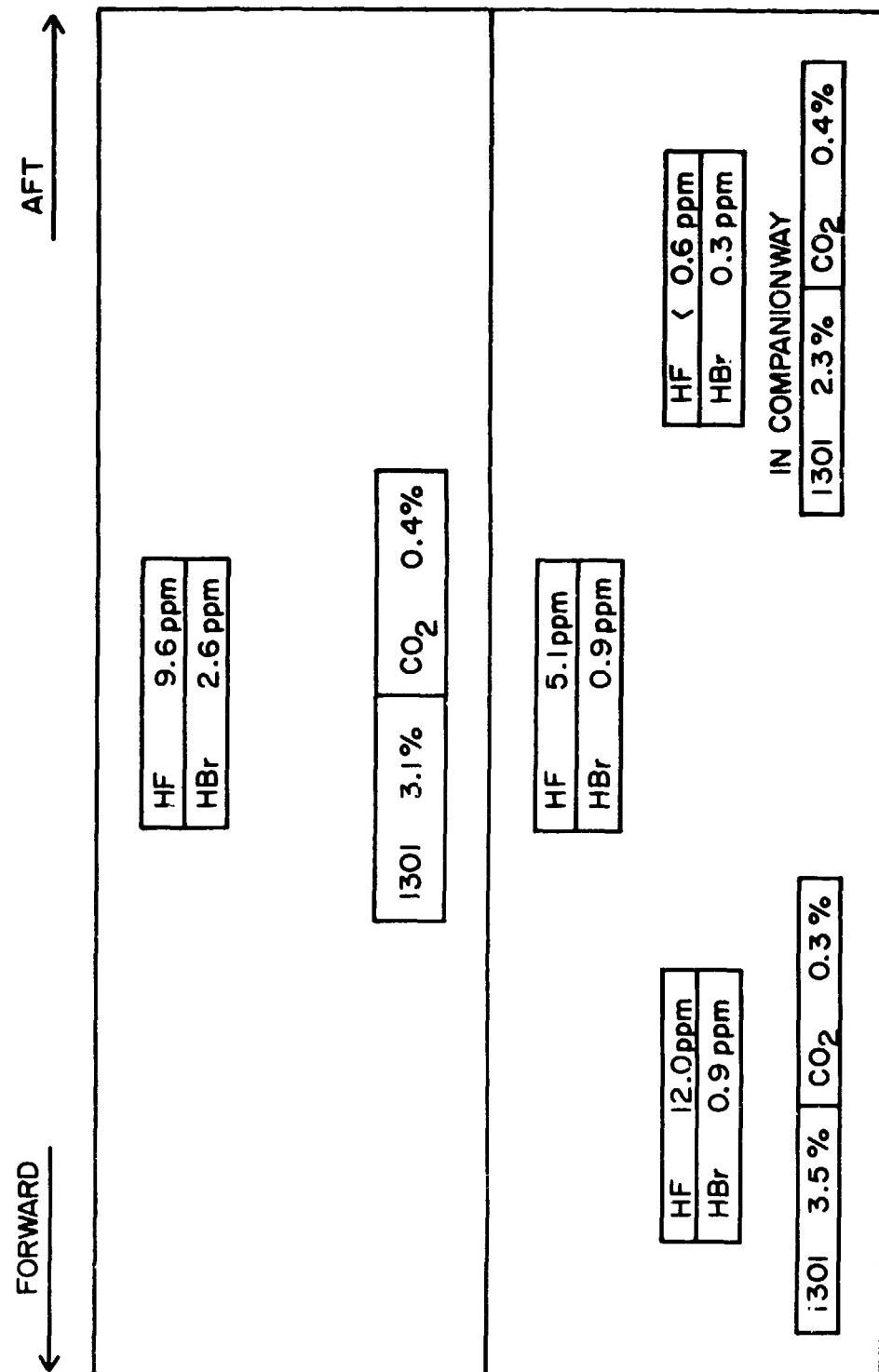


FIGURE 25. PRODUCTS OF DECOMPOSITION, TEST NO. 3.

NOV. 14, 1 MIN. 4.4% 1301, TC 1-6

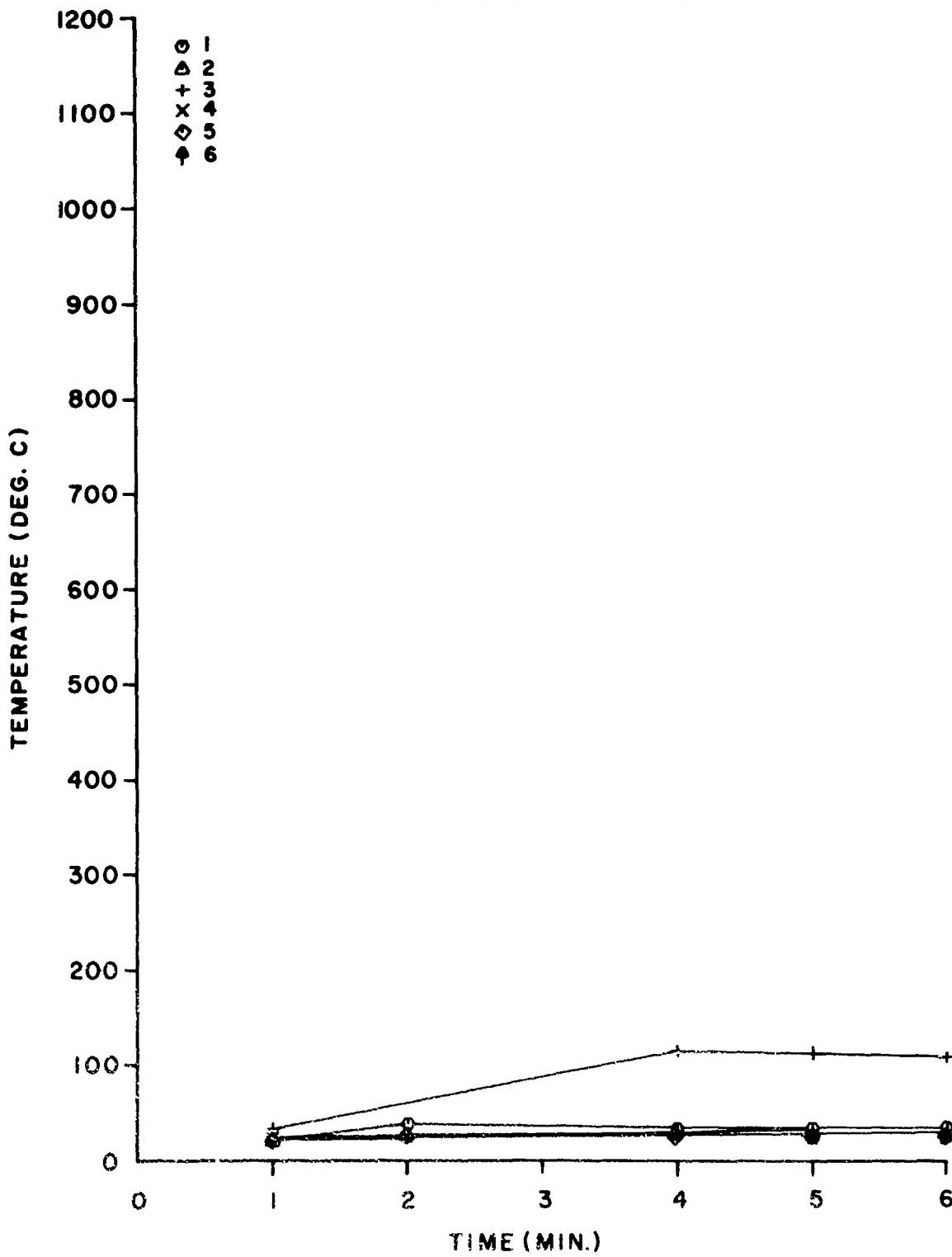


FIGURE 26. TEMPERATURES (TC 1-6), TEST NO. 3.

NOV. 14, 1 MIN. 4.4% 1301, TC 7-12

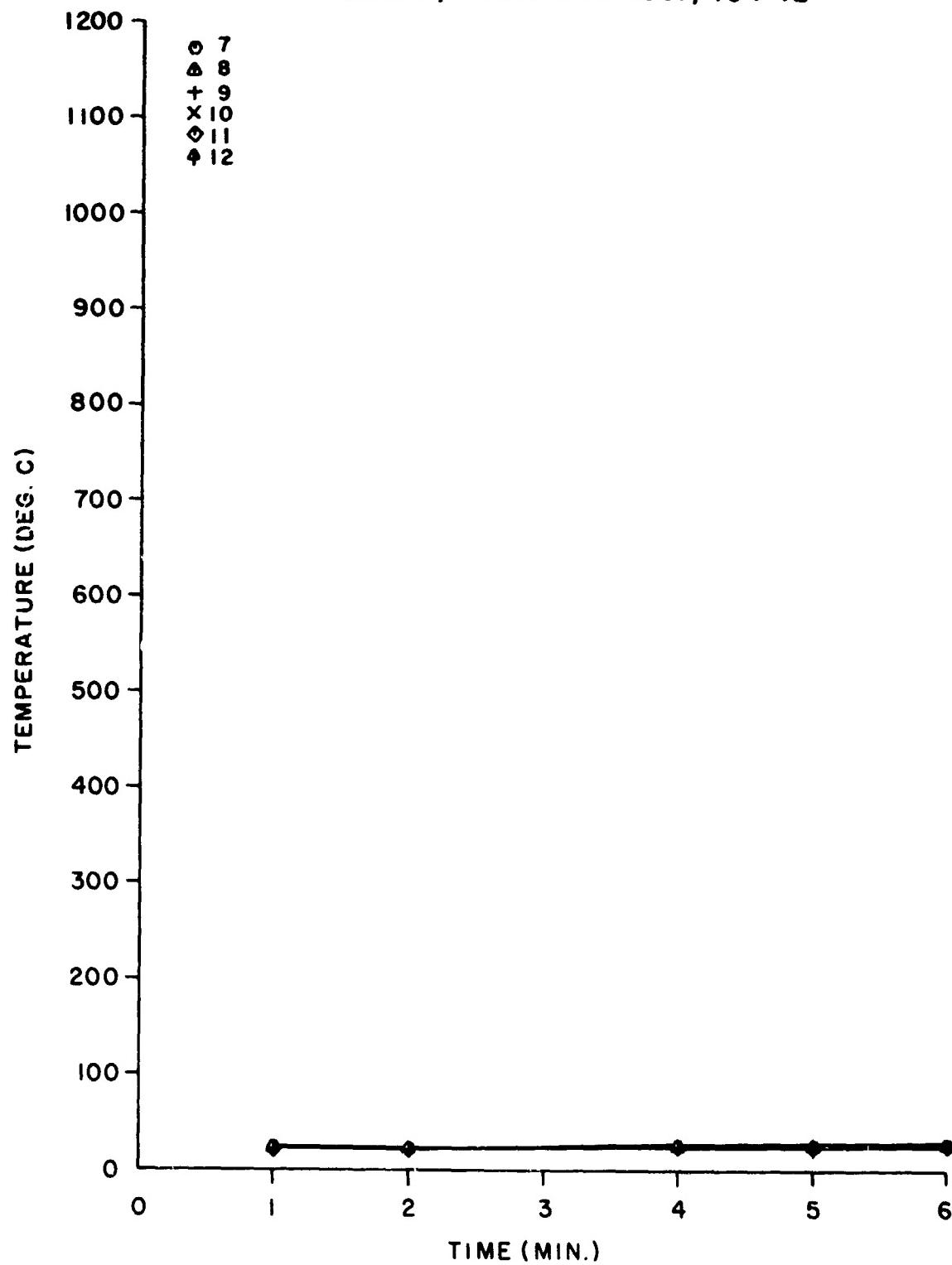


FIGURE 27. TEMPERATURES (TC 7-12), TEST NO. 3.

NOV. 14, 1 MIN. 4.4% 1301, TC 13-18

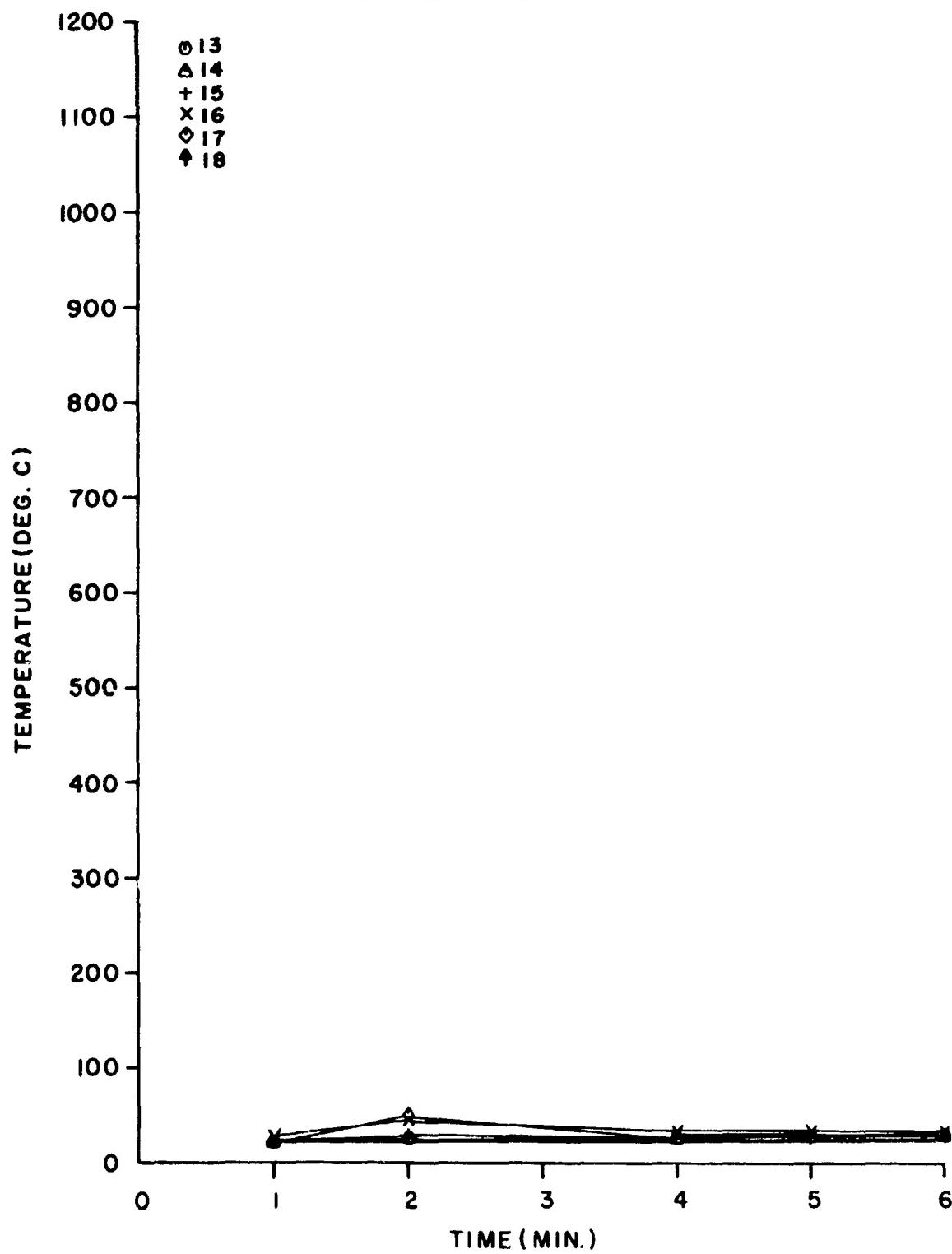


FIGURE 28. TEMPERATURES (TC 13-18), TEST NO. 3.

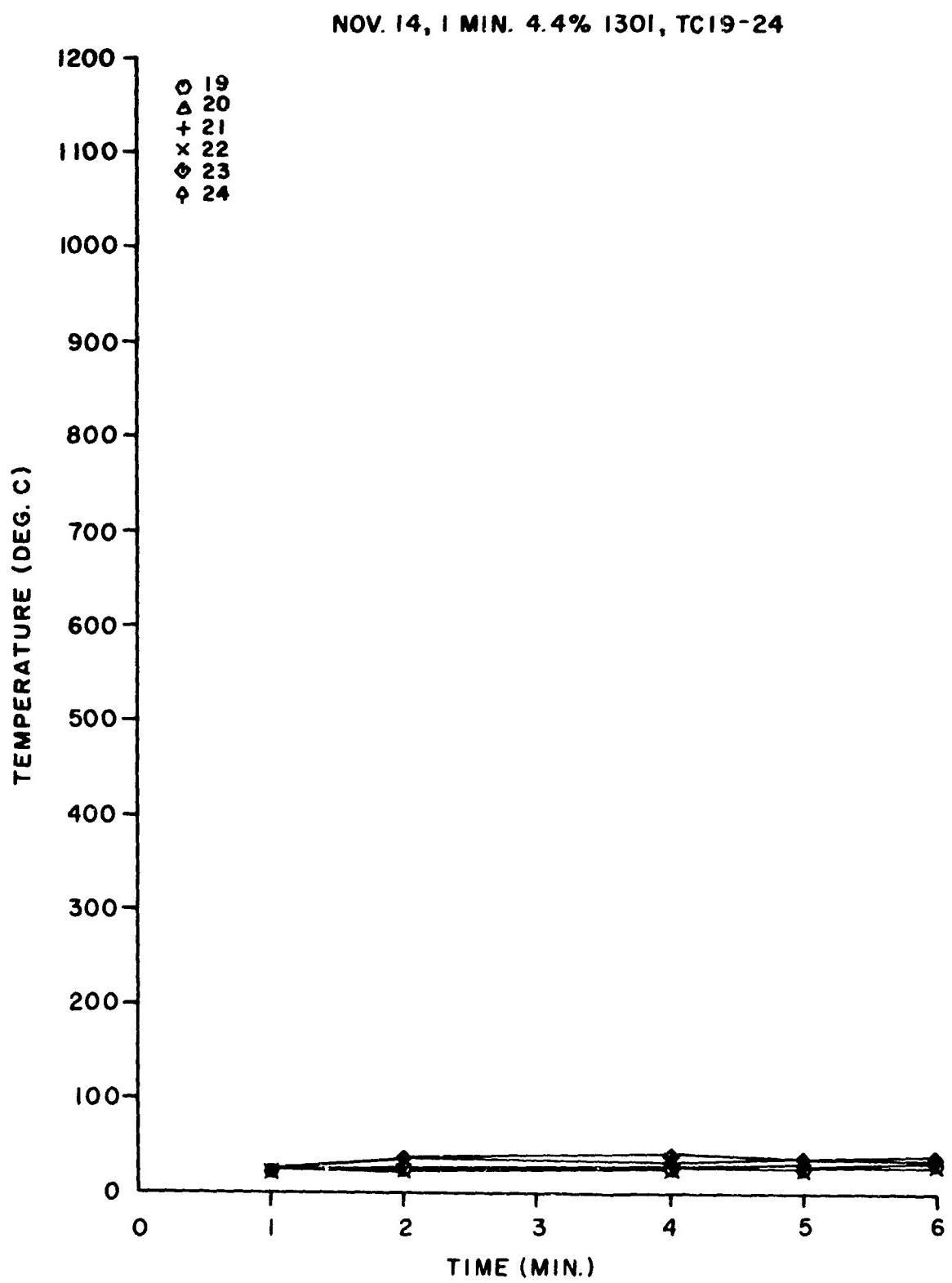


FIGURE 29. TEMPERATURES (TC 19-24), TEST NO. 3.

TEST NO. 4

DATE: November 14, 1970

LENGTH OF PREBURN: 20 minutes

DISCHARGE TIME: 10 seconds

AGENT CONCENTRATION: 5.65 percent, 2340 lbs of HALON 1301

TEST OBJECTIVES:

1. Simulate an engine room bilge fire of the maximum proportions that could be anticipated before HALON 1301 application.
2. Determine adequacy of HALON 1301 in a concentration of 5.65 percent to extinguish a fire of this magnitude.
3. Measure concentrations of HALON 1301, hydrogen fluoride, hydrogen bromide, carbon monoxide, carbon dioxide, and oxygen.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 60°F

Humidity: 70 percent

Wind Direction and Speed: W, 11 knots

Barometric Pressure: 29.65 in Hg

Ventilation:

1. Skylights closed.
2. Main ventilators open (6).
3. Two 37,500-cfm fans operating until discharge.
4. All ventilators closed prior to discharge, with the exception of one ventilator which was closed 3 minutes after discharge.

TEST SEQUENCE:

1. Marine diesel (primed with 10 gallons of naptha and methyl keytone) ignited.
2. Clock started with visual confirmation of ignition.
3. Carbon monoxide and oxygen concentrations continuously monitored.
4. Fans and air vents shutdown simultaneously with HALON 1301 discharge. (One vent remained open past the discharge time.)

5. HALON 1301 discharged at the 20-minute mark.
6. Sample of HALON 1301, oxygen, and carbon monoxide concentrations taken 40 seconds after discharge termination.
7. Sample of HF and HB_T taken 50 seconds after discharge termination.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION:

The HF and HB_T concentrations were unmeasured due to the destruction of the test apparatus. The author smelled the products of combustion and the indication was that the pyrolysis products obtained in this test were no more severe than those obtained in any of the previous tests (see Figure 30). The National Bureau of Standards gas analysis equipment failed during this test.

TEMPERATURE OBSERVATIONS:

Refer to Figures 31 through 34 for recorded temperature observations.

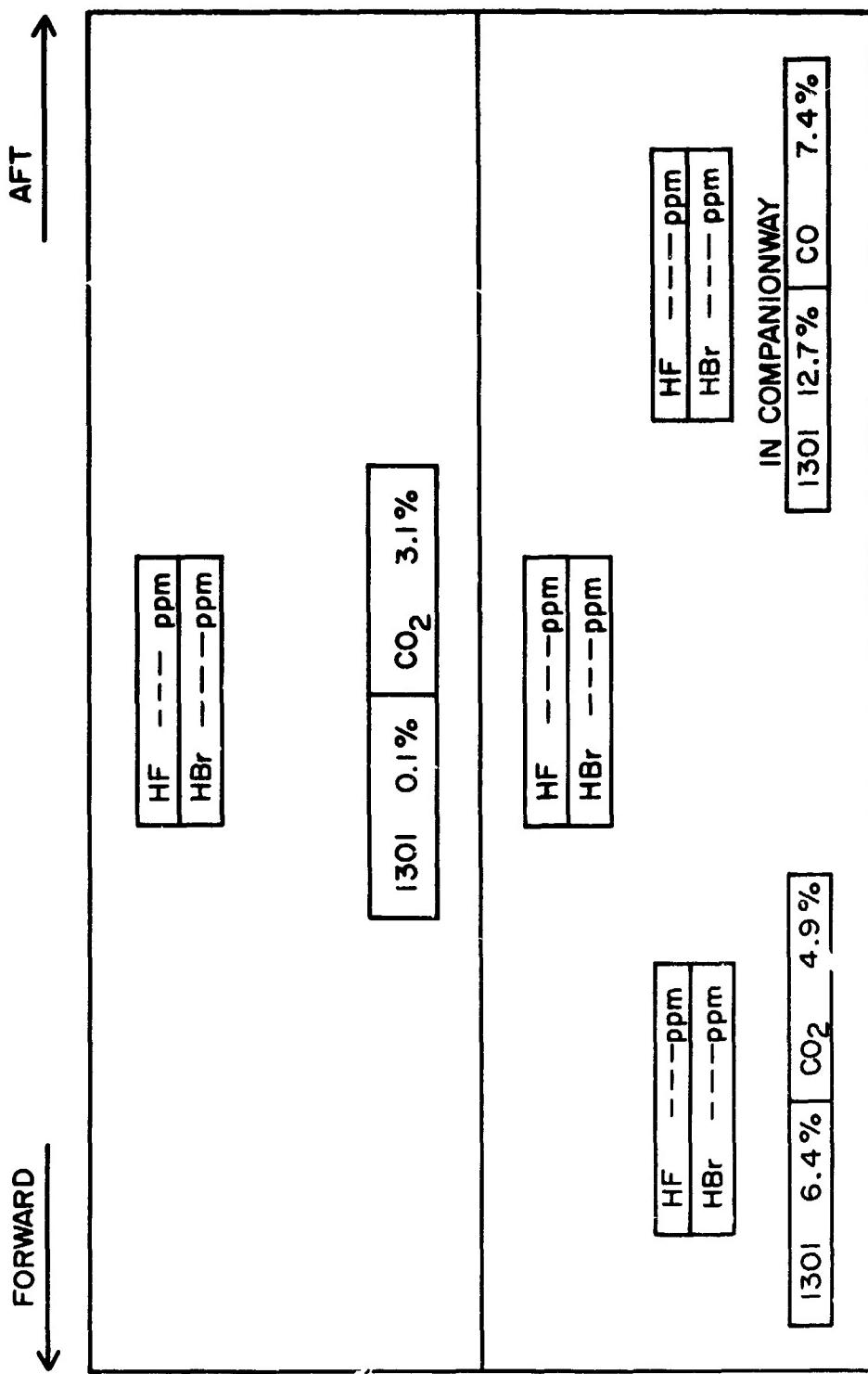
ANALYSIS:

1. This test was the most severe fire test to date (see Figures 31 through 34).
2. The piping was able to withstand the thermal shock without rupture or serious consequence (nozzles 2 and 5 were pointed downward).
3. Even with a ventilator open for 3 minutes after discharge, the HALON 1301 was capable of suppressing reflash.

CONCLUSIONS:

1. This fire was successfully extinguished with a concentration of 5.65 percent by volume of HALON 1301.
2. A fire of this size would surely leave the ship dead in the water, i.e., unable to sail under its own power.

FIGURE 30. PRODUCTS OF DECOMPOSITION, TEST NO. 4.



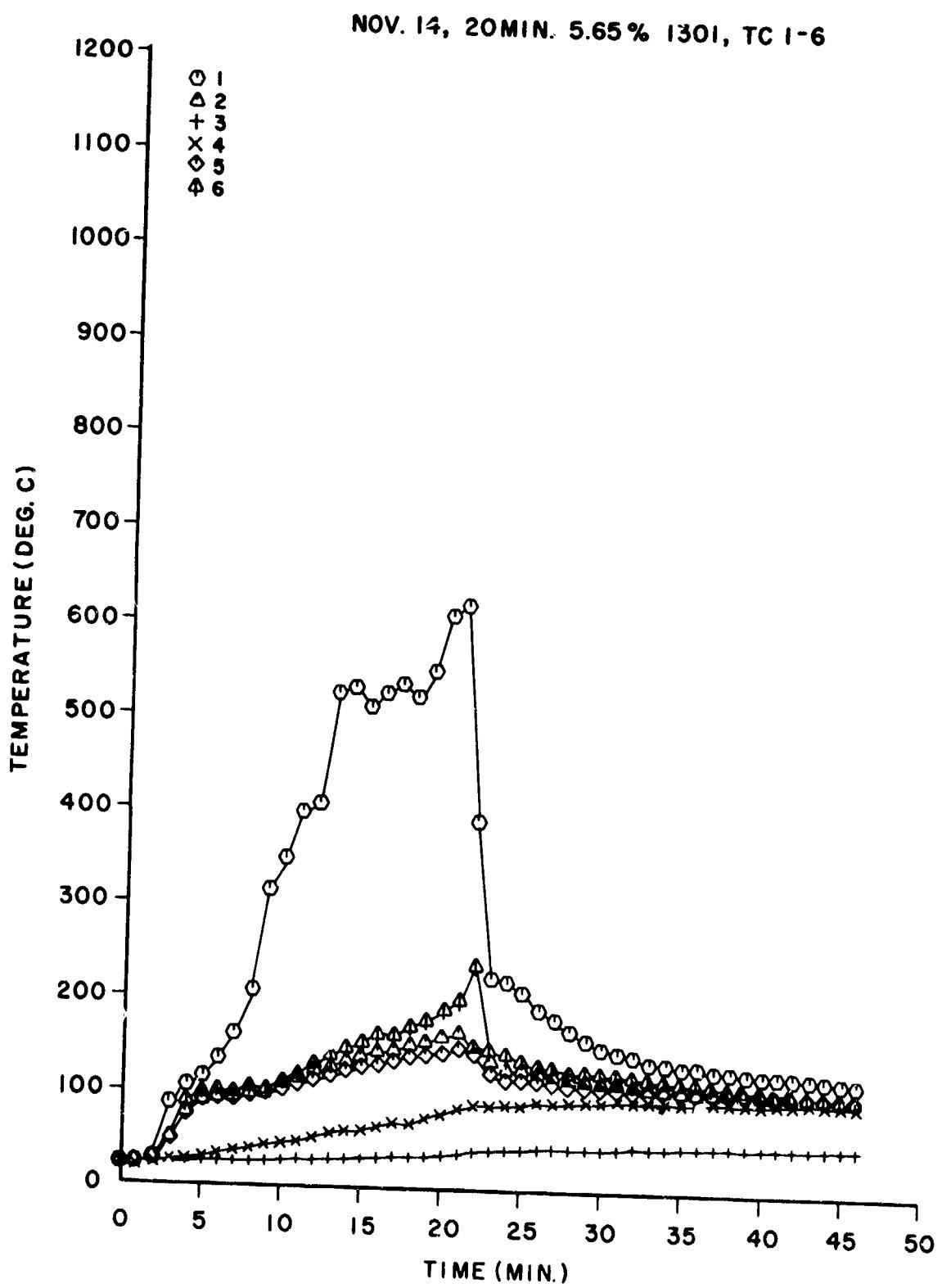


FIGURE 31. TEMPERATURES (TC 1-6), TEST NO. 4.

NOV. 14, 20 MIN. 5.65% I301, TC 7-12

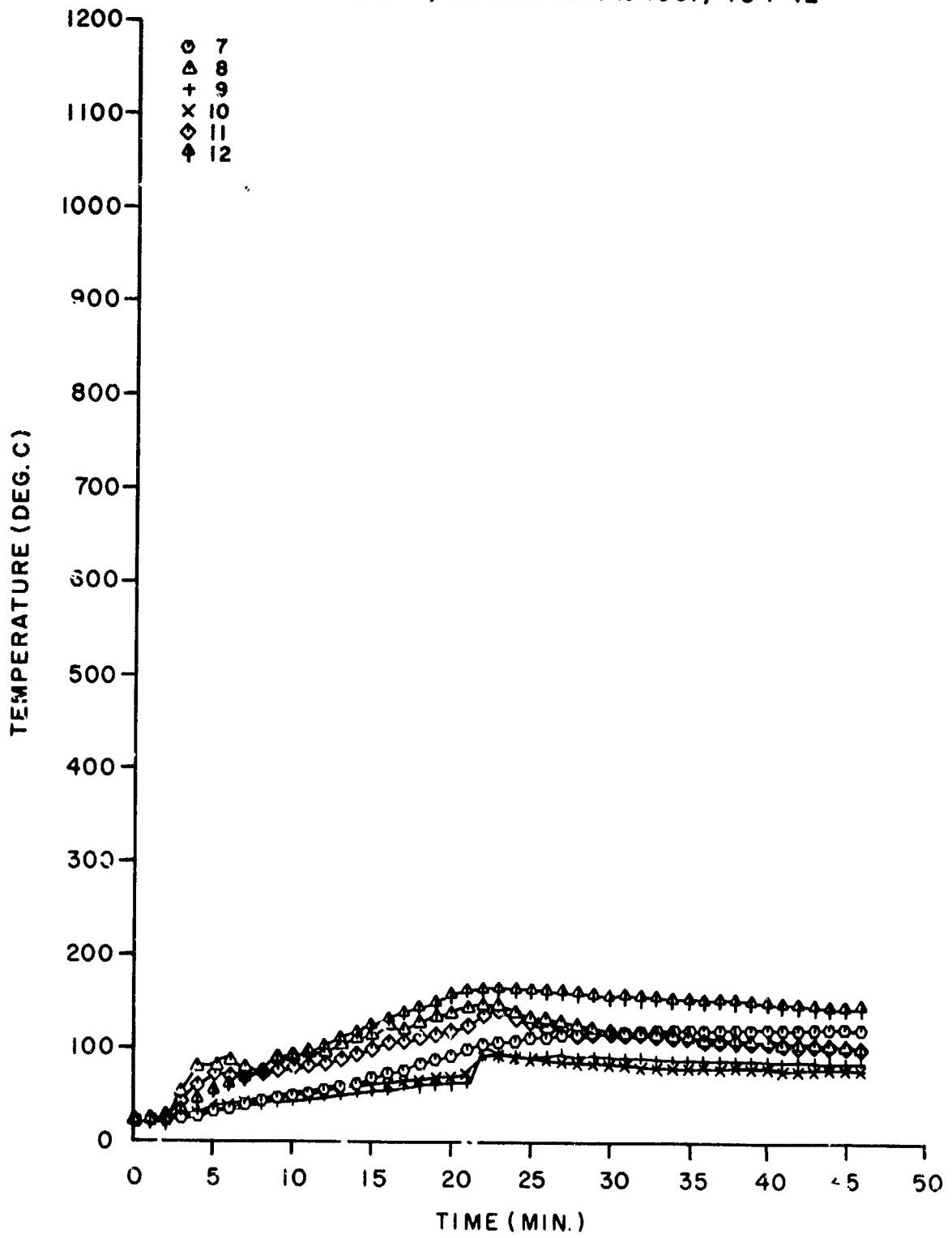


FIGURE 32. TEMPERATURES (TC 7-12), TEST NO. .

NOV. 14, 20 MIN. 5.65% 1301, TC 13-18

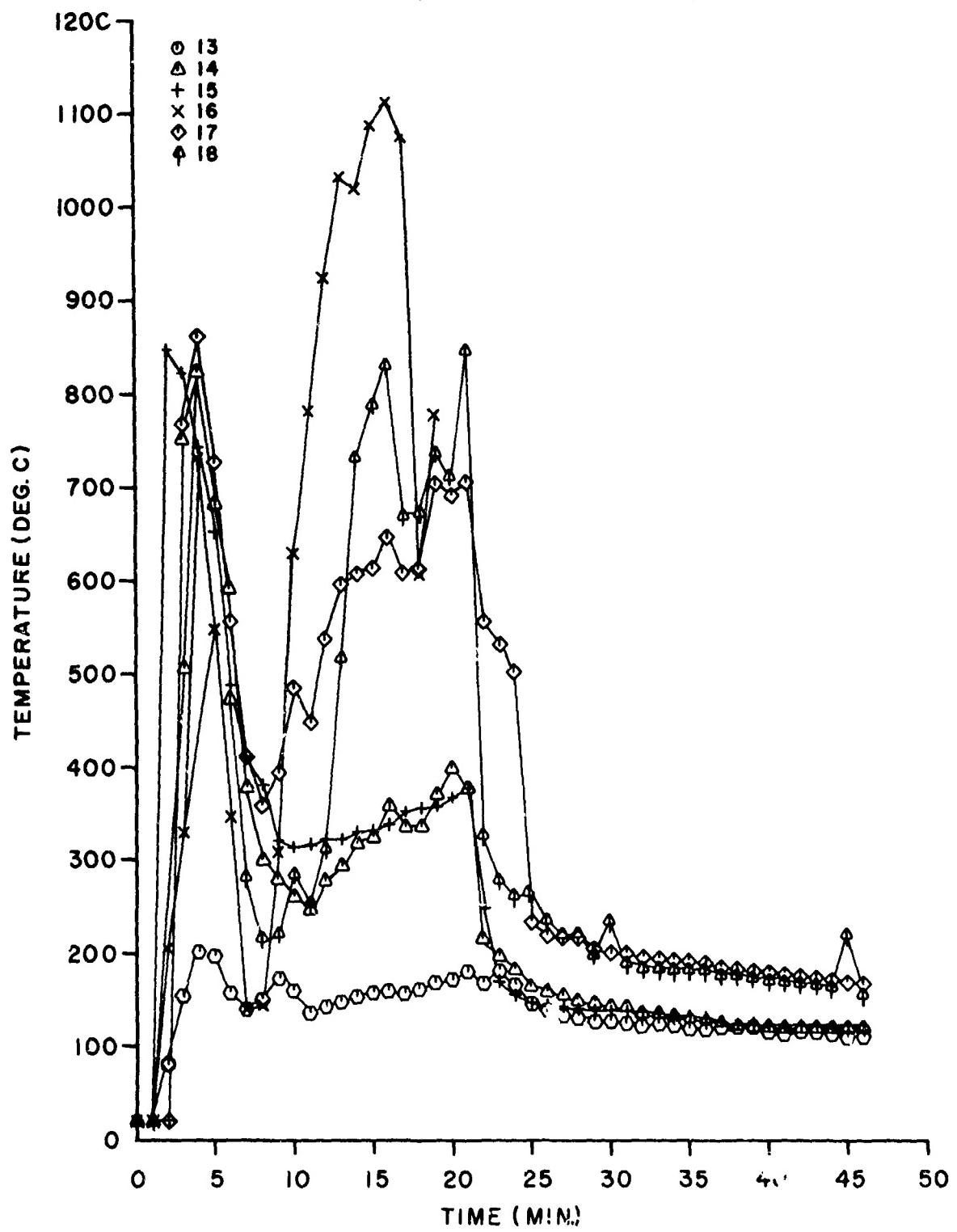


FIGURE 33. TEMPERATURES (TC 13-18), TEST NO. 4.

NOV. 14, 20 MIN. 5.65% 1301, TC 19-24

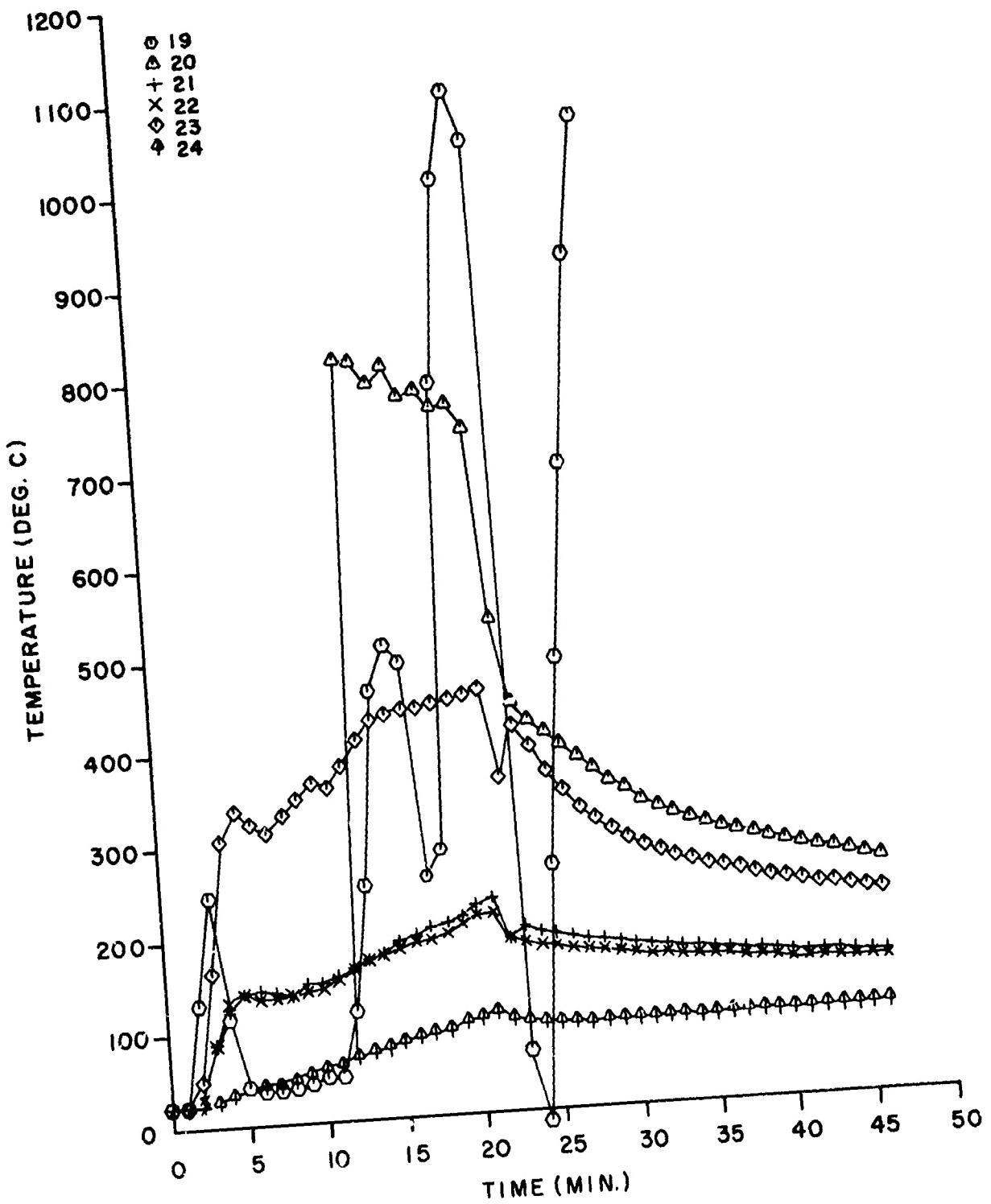


FIGURE 34. TEMPERATURES (TC 19-24), TEST NO. 4.

TEST NO. 5

DATE: November 19, 1970

LENGTH OF PREBURN: 1 minute

DISCHARGE TIME: 18 seconds

AGENT CONCENTRATION: 3.39 percent, 1371 lbs of HALON 1301

TEST OBJECTIVES:

1. Determine effectiveness of a heated, low pressure storage system for HALON 1301 discharge through a piping system designed for carbon dioxide.
2. Simulate an engine room bilge fire.
3. Determine effect of lengthening discharge time on the production of HALON 1301 decomposition products.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 67°F

Humidity: 90 percent

Wind Direction and Speed: SW, 11 knots

Barometric Pressure: 29.72 in Hg

Ventilation:

1. Skylights closed.
2. Main ventilators open.
3. Two 37,500-cfm fans operating until HALON 1301 was discharged.

TEST SEQUENCE:

1. Marine diesel ignited (four ignitors, fuel was primed with 5 gallons of naptha and methylethyl ketone).
2. Clock started with visual confirmation of ignition.
3. Intake fans started simultaneously with confirmation of ignition.
4. Fans and vents shutdown coincident with HALON 1301 discharge.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION:

Concentrations of HF and HB_f obtained are shown in Figure 35. The HF and HB_f concentrations were lower in this test than in any previous test. Concentrations of HALON 1301 were recorded on a continuous strip recorder furnished by the Cardox Company. Figure 36 illustrates the HALON 1301 concentrations.

TEMPERATURE OBSERVATIONS:

Refer to Figures 37 through 40 for recorded temperature observations.

ANALYSIS:

Temperature analysis indicates that this test fire was of the same order of magnitude as the fire in Test No. 3 (significantly smaller than the previous 10 or 20-minutes preburns). The test fire was accompanied by appreciable volumes of smoke, but the fire did not develop enough heat to make the thermocouple rise.

CONCLUSIONS:

1. The test fire was successfully extinguished with a concentration of 3.39 percent by volume of HALON 1301.
2. The downward-directed nozzles distributed high concentrations of HALON 1301 agent at the lower levels.
3. The longer discharge time with a reduced quantity of HALON 1301, and downward-directed nozzles, does not achieve uniform mixing.

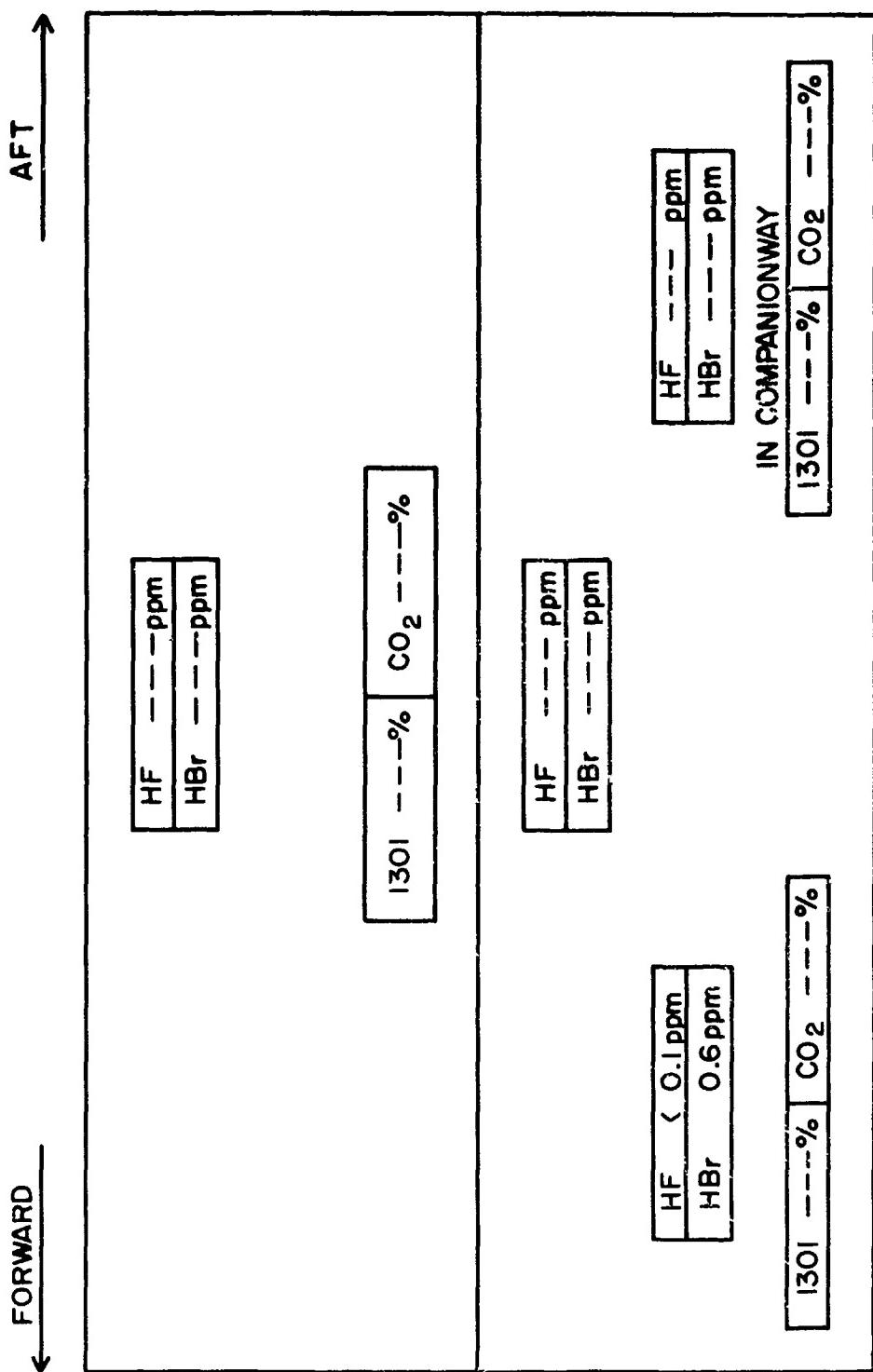


FIGURE 35. PRODUCTS OF DECOMPOSITION, TEST NO. 5.

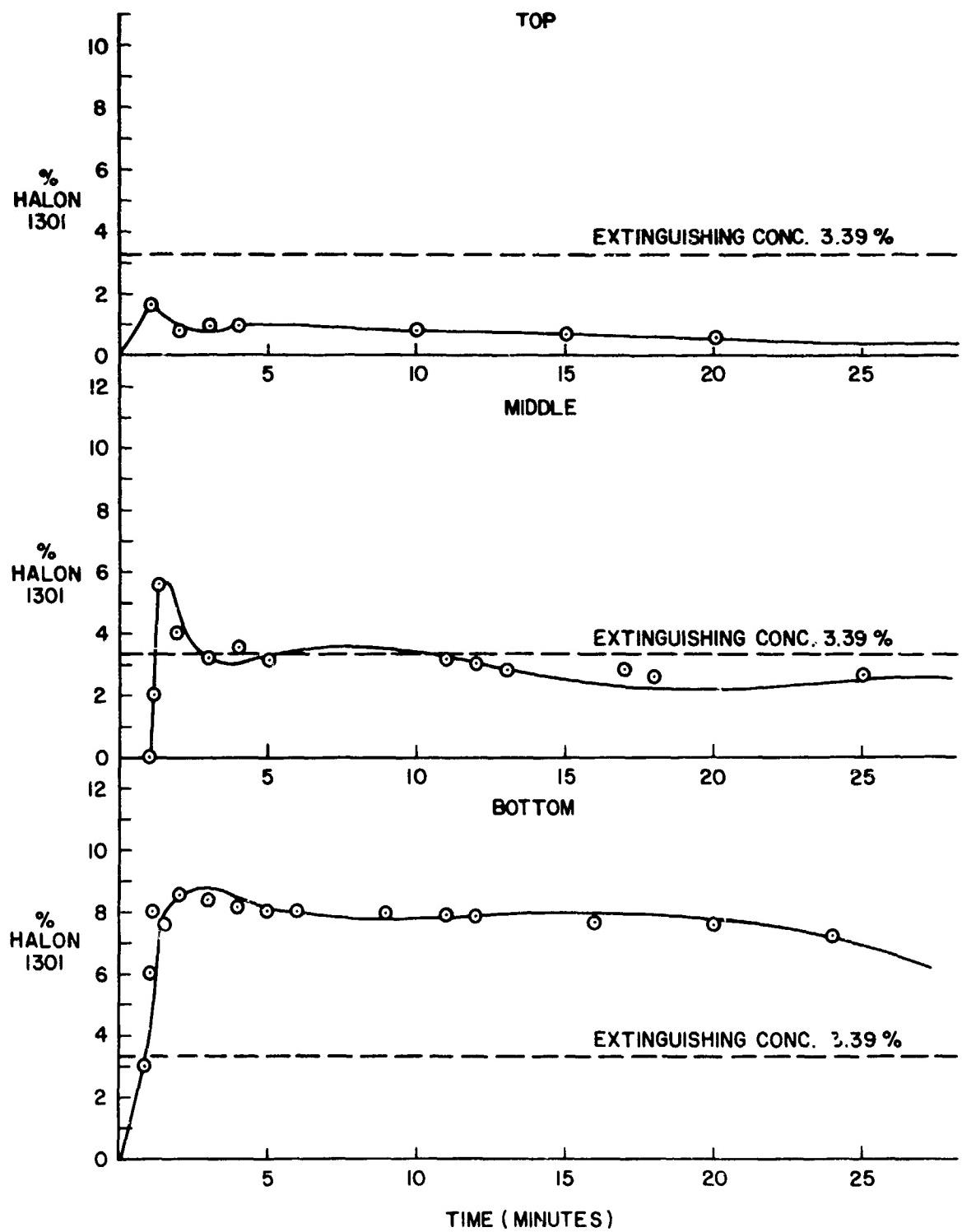


FIGURE 36. HALON 1301 CONCENTRATIONS VS. TIME, TEST NO. 5.

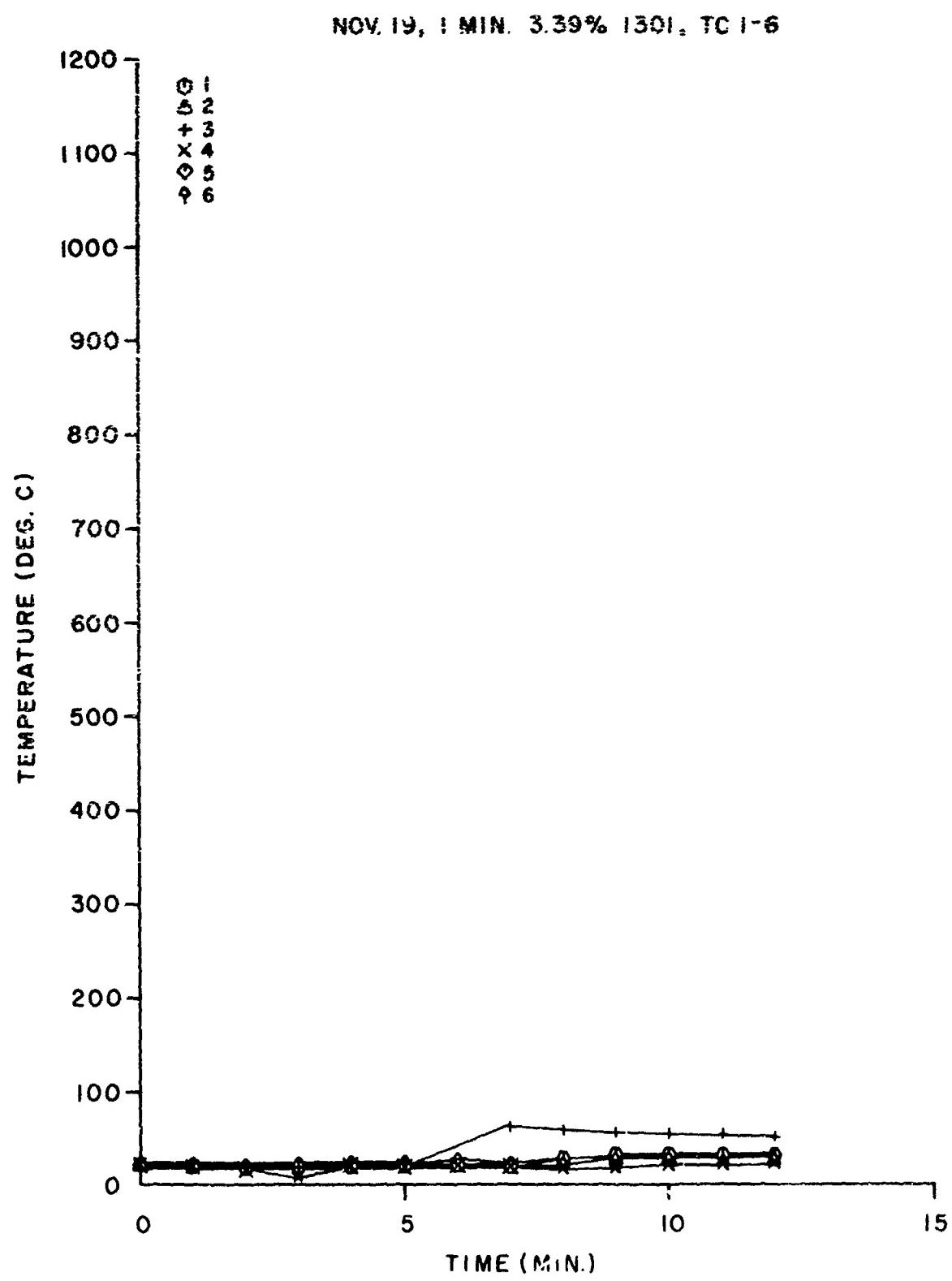


FIGURE 37. TEMPERATURES (TC 1-6), TEST NO. 5.

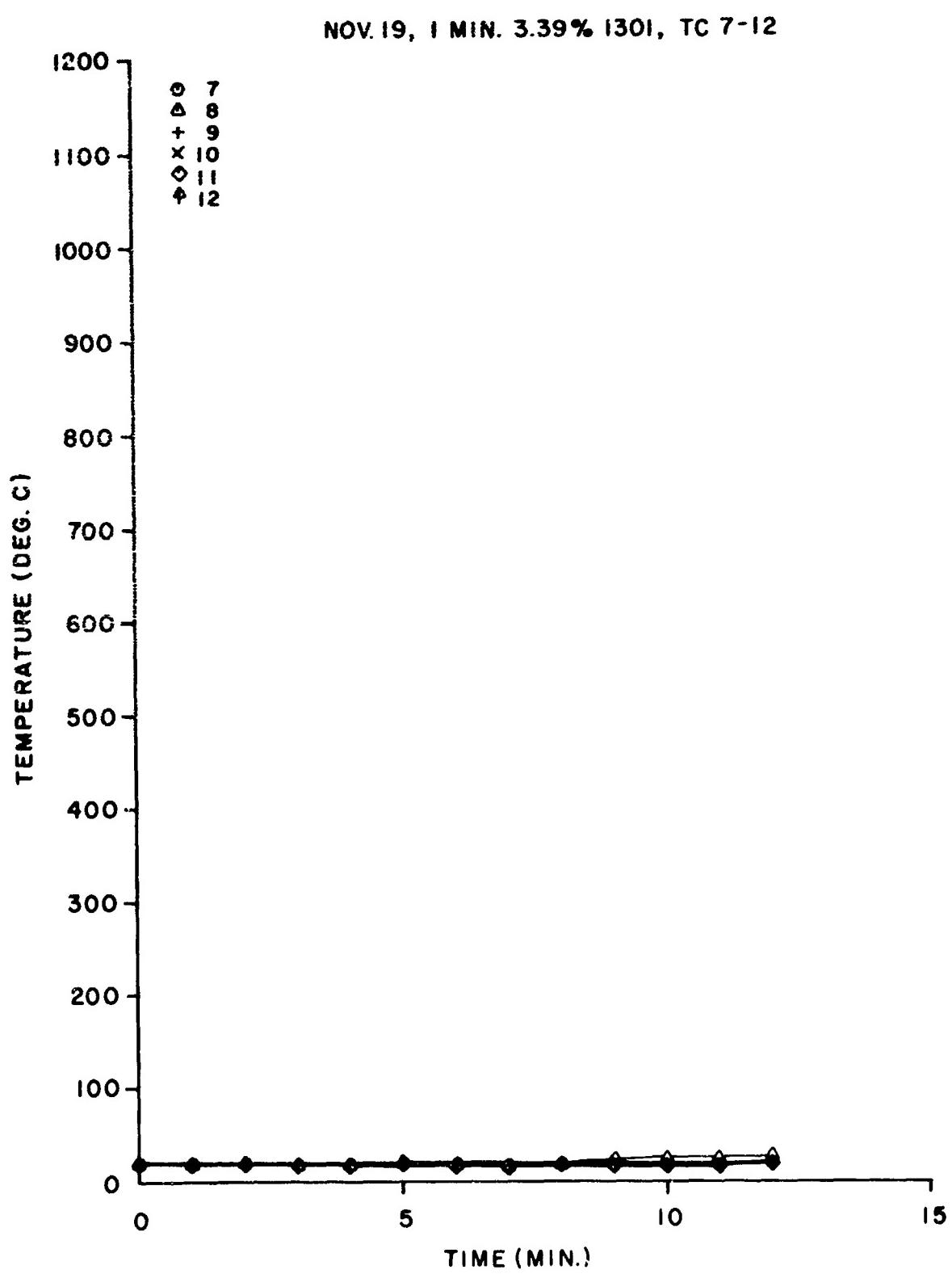


FIGURE 38. TEMPERATURES (TC 7-12), TEST NO. 5.

NOV. 19, 1 MIN. 3.39% 1301, TC 13-18

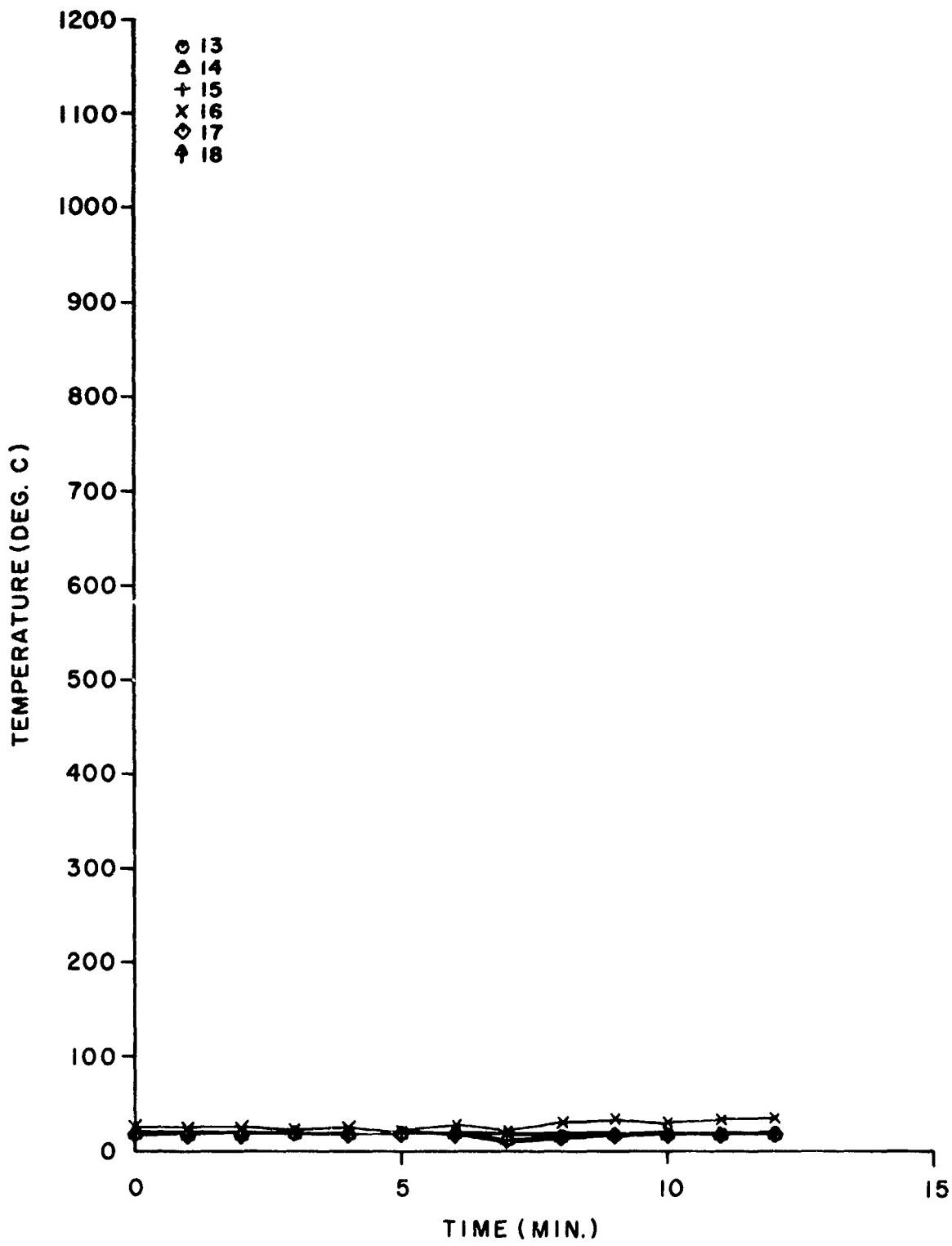


FIGURE 39. TEMPERATURES (TC 13-18), TEST NO. 5.

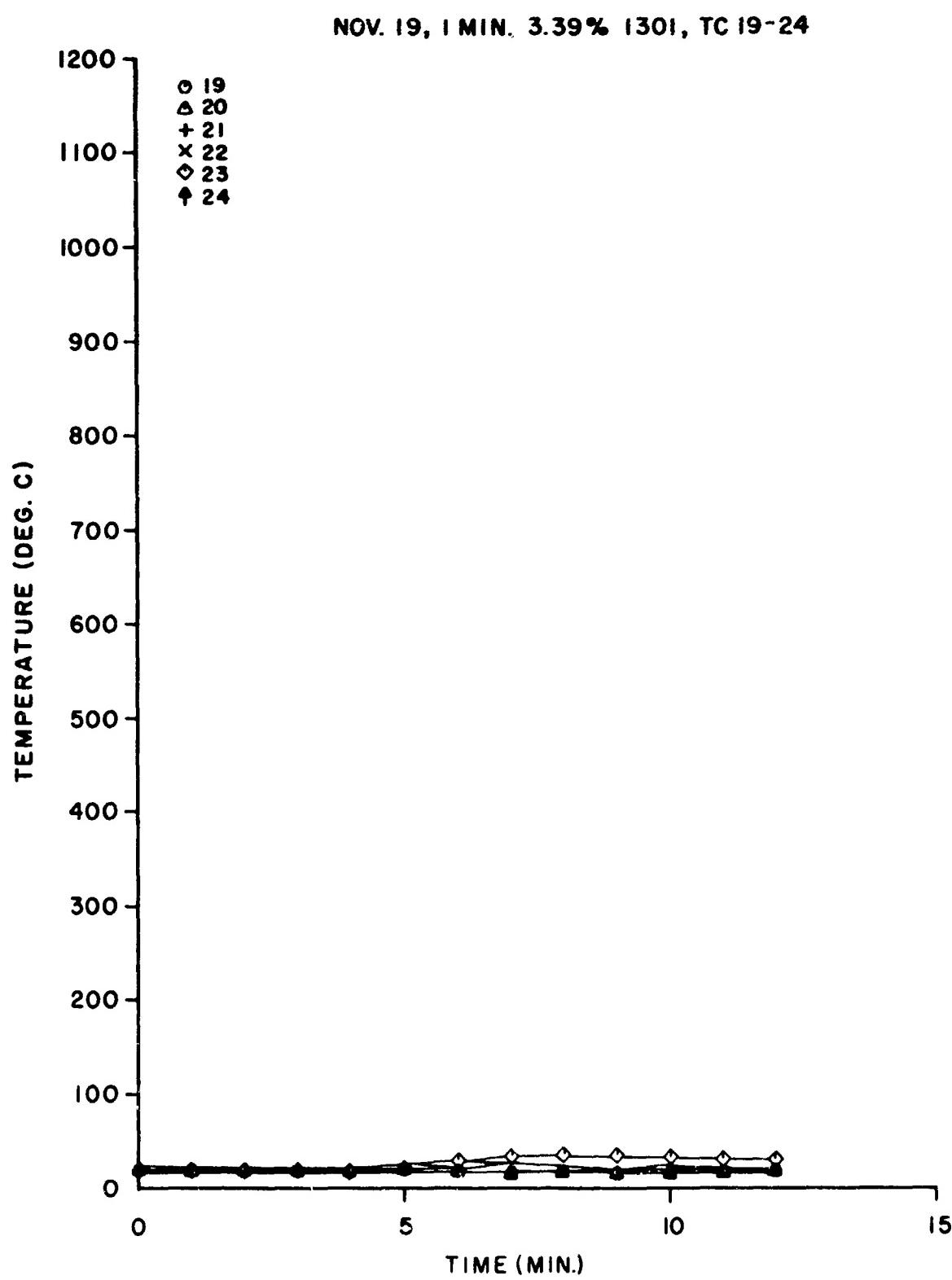


FIGURE 40. TEMPERATURES (TC 19-24), TEST NO. 5.

TEST NO. 6

DATE: November 19, 1970

LENGTH OF PREBURN: 10 minutes

DISCHARGE TIME: 28 seconds

AGENT CONCENTRATION: 4.64 percent, 1903 lbs of HALON 1301

TEST OBJECTIVES:

1. Simulate an engine room bilge fire.
2. Determine HALON 1301 effectiveness in a concentration of 4.64 percent.
3. Determine effect of lengthening discharge time on HALON 1301 effectiveness and the production of HALON 1301 decomposition products.

ENVIRONMENTAL CONDITIONS:

Weather:

Temperature: 76°F

Humidity: 58 percent

Wind Direction and Speed: S, at 18 knots

Barometric Pressure: 29.72 in Hg

Ventilation:

1. Skylights closed.
2. Main ventilators open (6).
3. Two 37,500-cfm fans operating until discharge.
4. All ventilators closed prior to discharge.

TEST SEQUENCE:

1. Marine diesel ignited (primed with 5 gallons of methylethyl ketone).
2. Two intake fans started immediately after confirmation of ignition.
3. Carbon monoxide and oxygen concentration continuously monitored.
4. Fans and air vents secured simultaneously with HALON 1301 discharge.
5. HALON 1301 discharged at 10-minute mark.
6. Samples of HALON 1301, air, and carbon monoxide concentrations taken 40 seconds after discharge termination.
7. Samples of HF and HB_r taken 50 seconds after discharge termination.

MEASUREMENT OF HALON 1301 PRODUCTS OF DECOMPOSITION:

The HF and HB_r concentrations are shown in Figure 41. These concentrations were the highest recorded during the test program. HALON 1301 concentrations are shown in Figure 42.

TEMPERATURE OBSERVATIONS:

Refer to Figures 43 through 46 for recorded temperature observations.

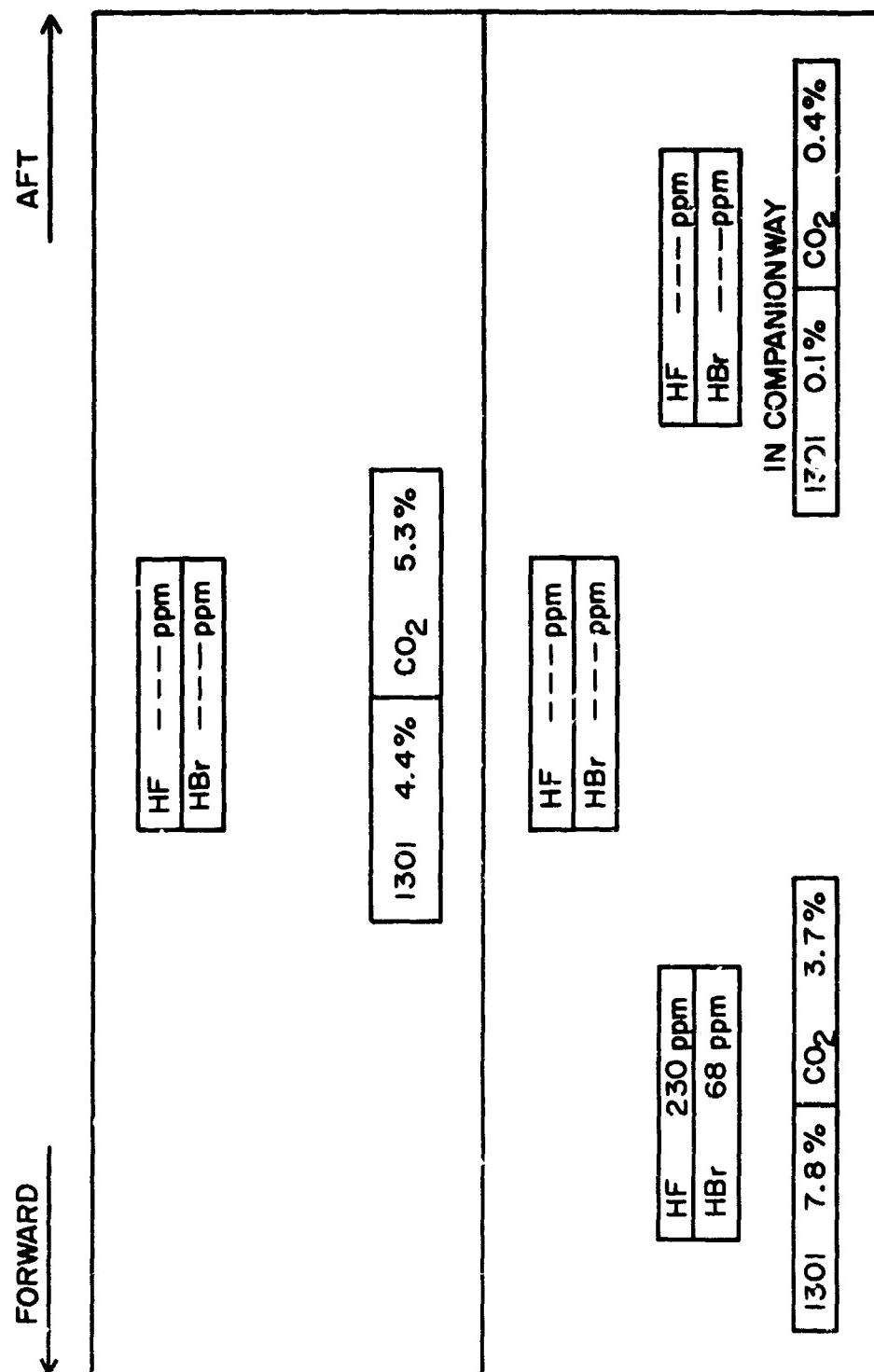
ANALYSIS.

1. This test fire was the second-hottest fire of the program.
2. The fire was limited primarily to the forward sections of the engine room.
3. The temperature drop after HALON 1301 discharge was extremely rapid.

CONCLUSIONS:

1. The fire was successfully extinguished with a HALON 1301 concentration by volume c 4.54 percent.
2. Lengthening the discharge time causes a more than proportional increase in the amount of HF and HB_r.
3. Examining the HALON 1301 distribution data indicates adequate mixing with this system can be achieved if a sizeable fire occurs.

FIGURE 41. PRODUCTS OF DECOMPOSITION, TEST NO. 6.



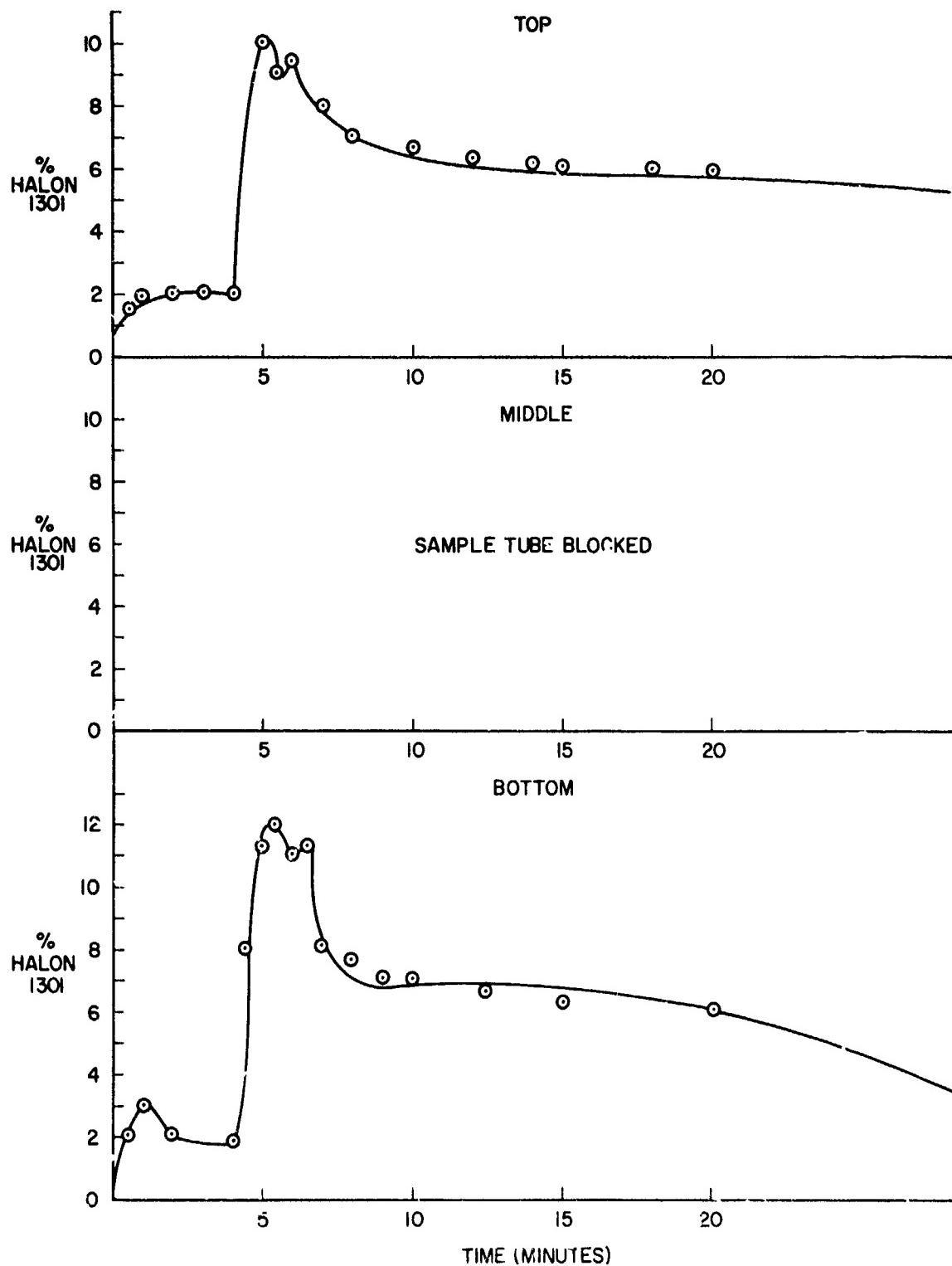


FIGURE 42. HALON 1301 CONCENTRATIONS VS TIME, TEST NO. 6.

NOV. 19, 10 MIN. 4.64 % 1301, TC 1-6

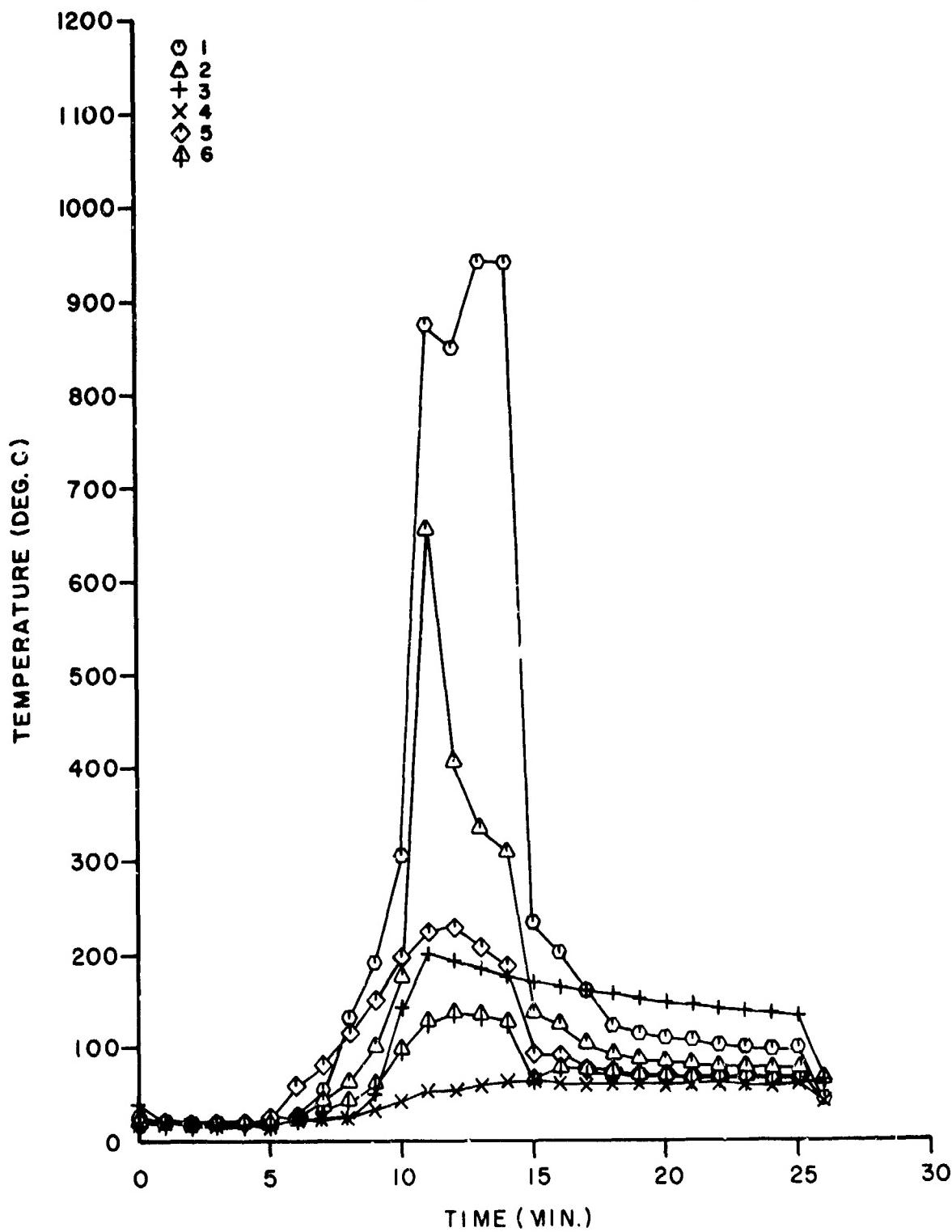


FIGURE 43. TEMPERATURES (TC 1-6), TEST NO. 6.

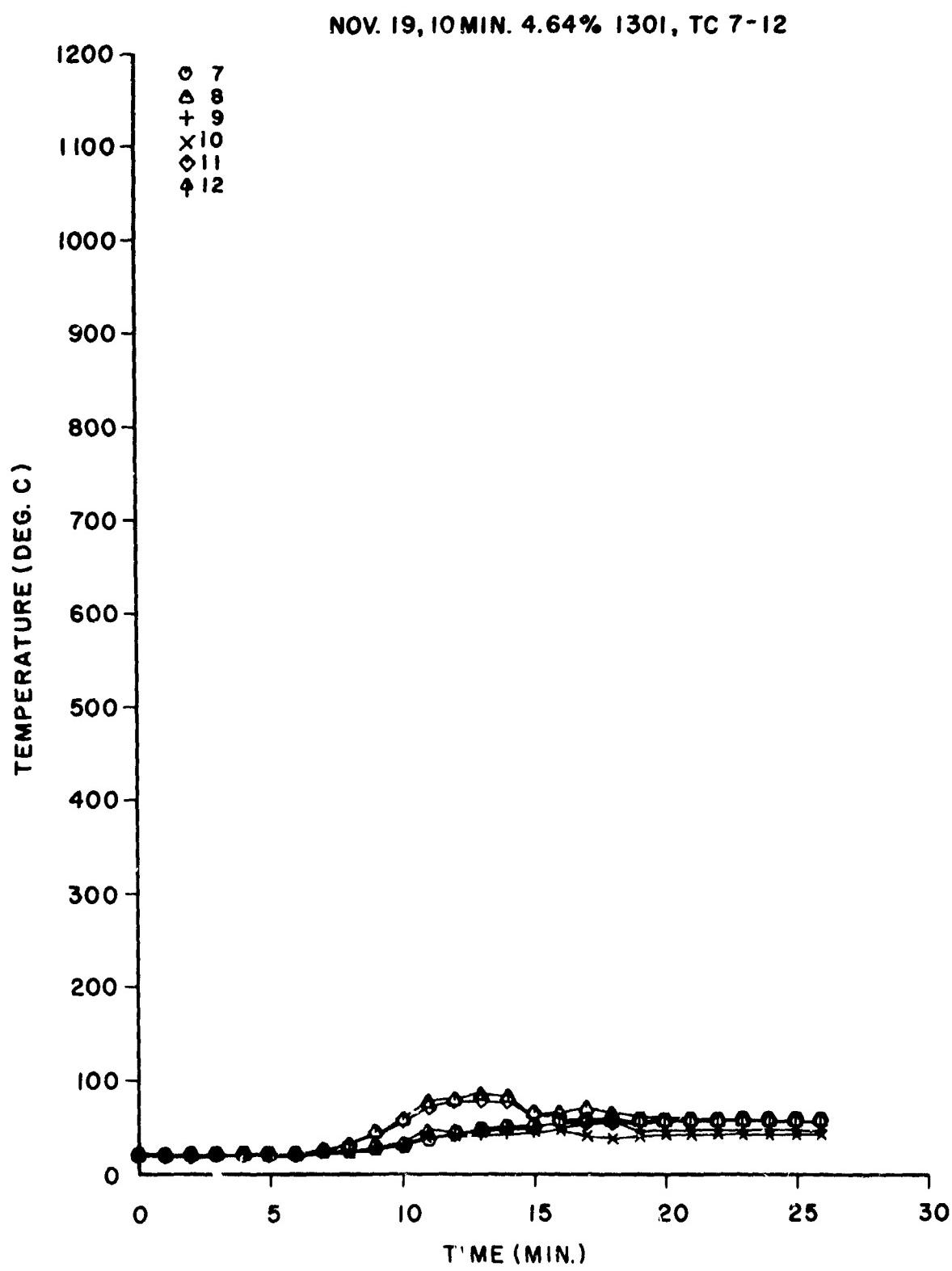


FIGURE 44. TEMPERATURES (TC 7-12), TEST NO. 6.

NOV. 19, 10 MIN. 4.64% 1301, TC 13-18

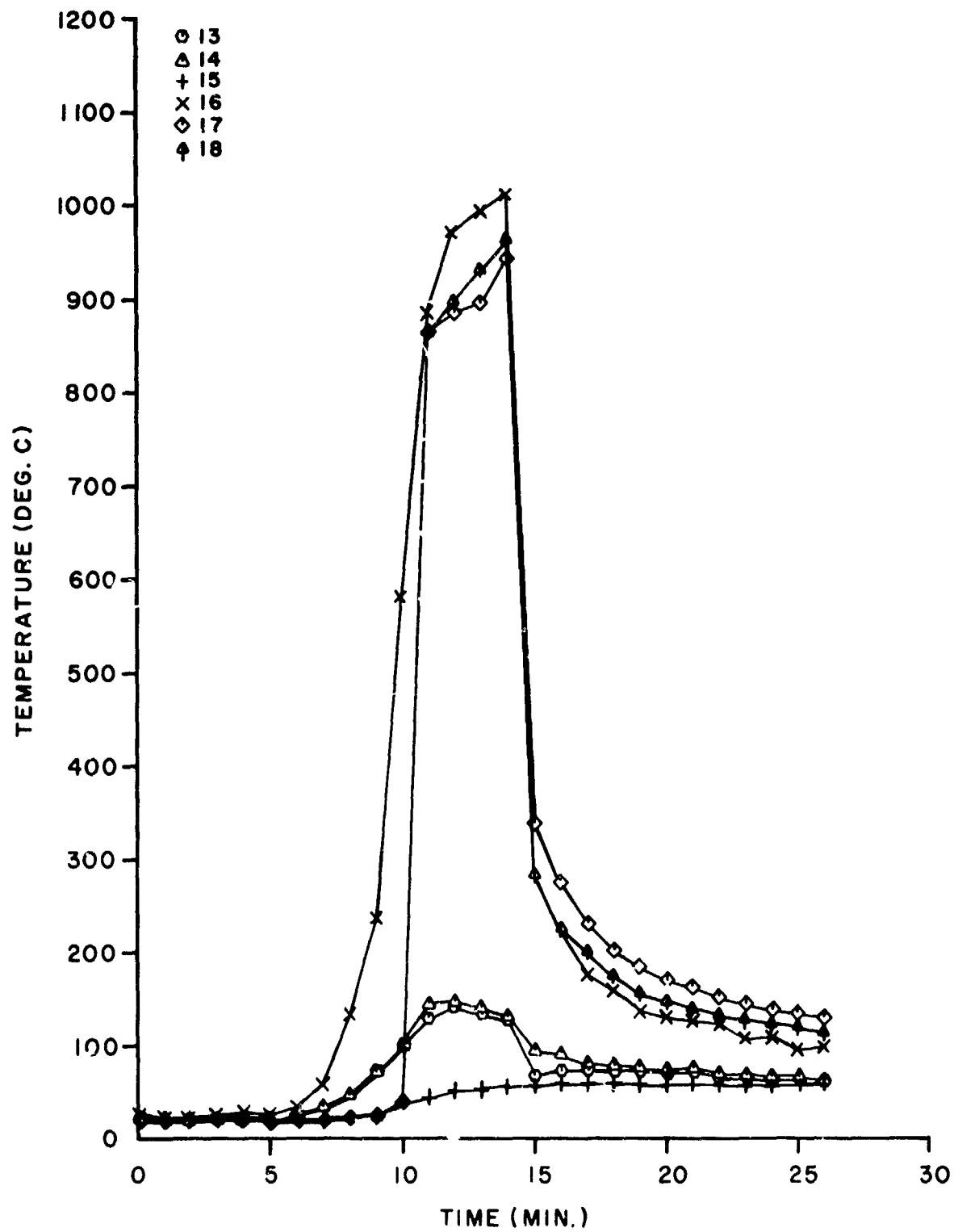


FIGURE 45. TEMPERATURES (TC 13-18), TEST NO. 6.

NOV. 19, 10 MIN. 4.64% 1301, TC 19-24

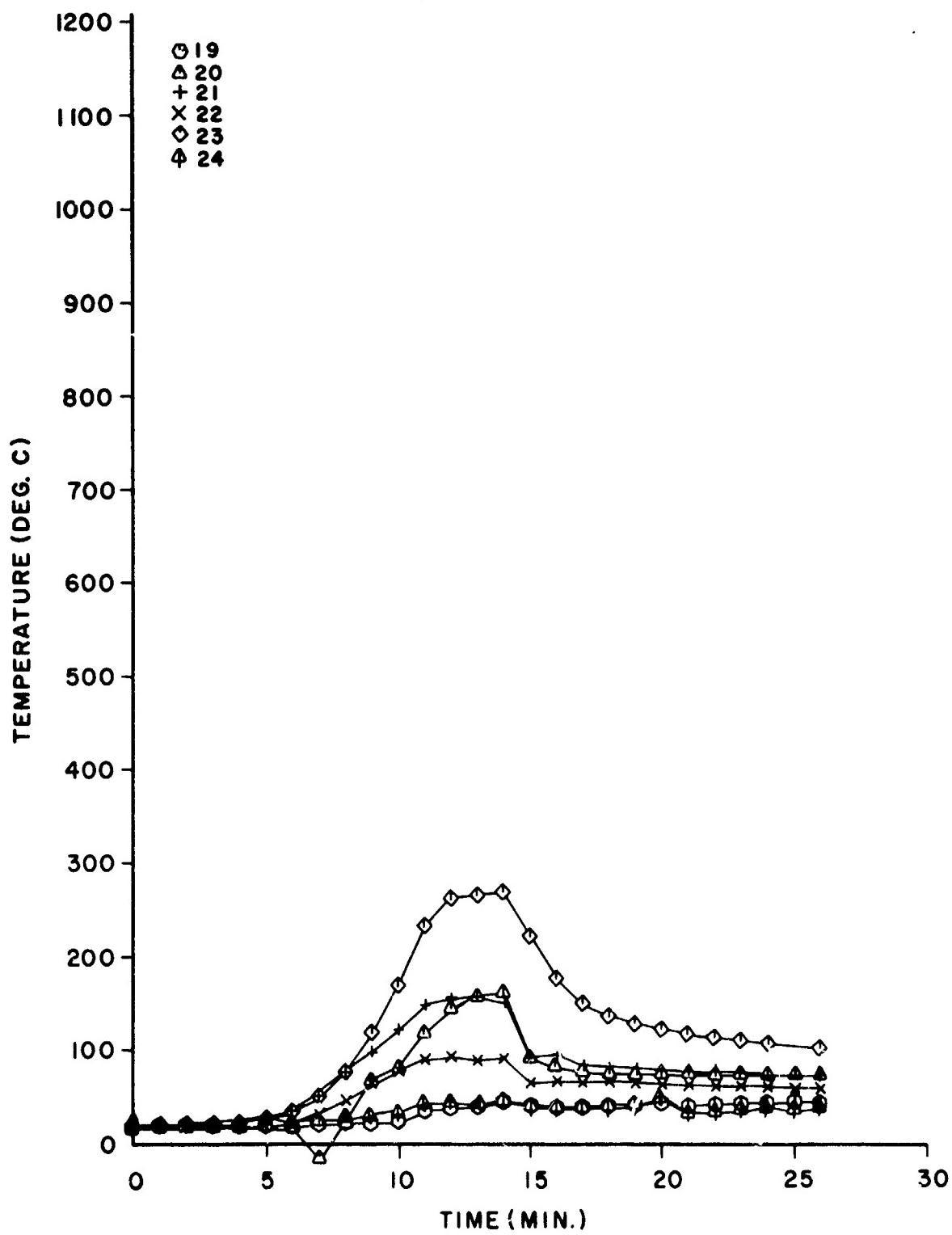


FIGURE 16. TEMPERATURES (TC 19-24), TEST NO. 6.

DISCUSSION OF MACHINERY SPACE ATMOSPHERIC CONDITIONS

OXYGEN LEVELS. If the oxygen concentration in an enclosed space is lowered from the 21 percent normal to 15 percent or less, flammable liquid fires will be extinguished. Ideally the ship's machinery space may be made airtight, within reasonable limits, so that total-flooding extinguishing agents may be effectively applied. Theoretically, if the space were 100 percent airtight the fire would extinguish itself. However, this is not the actual case and practicality prevents achieving this goal. Therefore, a total flooding system combined with controlled ventilation can be very effective in extinguishing machinery space fires. Extinguishing concentrations must be maintained for a sufficient period to allow the maximum temperature to be reduced below the autoignition temperature of the burning material. (The auto ignition temperature of marine diesel is approximately 600°F [8].

TEST OBSERVATIONS. Oxygen concentrations were measured in fire tests No. 1 and No. 2. Equipment breakdown prevented measurement in subsequent tests; however, the observations made are based not only on tests No. 1 and No. 2, but also on a series of carbon dioxide tests which were conducted prior to this test program.

Oxygen Starvation. The test fires were limited by oxygen starvation which began at the 10-minute mark and usually continued until the HALON 1301 had been introduced. The one obvious exception occurred in test No. 4. A review of the temperatures (see Figures 31 through 34) indicates that there was an initial rapid combustion buildup which depleted the oxygen in the space. The oxygen was then replenished via the fire draft conditions and the continuous operation of two 37,500-cfm fans.

Ventilation Secured. The two fans were operated during each HALON 1301 test, but in tests No. 1 and No. 2, the fans were secured 1 minute prior to HALON 1301 discharge. Securing the fans resulted in an immediate reduction of fire intensity, as reported by NBS test van personnel. In subsequent tests, the time between fan securing and ventilator covering was decreased to less than 30 seconds in order to present as severe a fire as possible to the HALON 1301.

HALON 1301 DECOMPOSITION PRODUCTS AND TOXIC COMBUSTION PRODUCTS

MEASURED CONCENTRATIONS. The test results indicated concentrations of HF and HB_r ranged from 0.1 to 230 ppm and 0.6 to 68 ppm, respectively, depending upon HALON 1301 discharge time. There has been increasing controversy over the production, severity, and effect of the primary decomposition products (HF and HB_r) of HALON 1301. A benchmark for determining the severity of these two decomposition products is to compare the amounts produced, and the approximate lethal concentrations, to the normal combustion gasses produced during a fire. An oil fire given adequate oxygen for complete combustion would produce carbon dioxide. However, incomplete combustion occurs in the majority of oil fires, and this was the case as pointed out previously for the machinery space fires aboard the M/V RHODE ISLAND. NFPA FIRE PROTECTION HANDBOOK, 13th ed., states that "A person who is exposed to a 1.28 percent concentration of carbon monoxide in air will become unconscious after two to three breaths and probably die in one to two minutes." (10) Product concentrations were measured by an MSA fire gas analyzer (Model 300) with a maximum scale reading of 0.2 percent (2000 ppm). Gas analyzer failure occurred after the third test in the program; however, the analyzer reading was off scale at 6-1/2 minutes, 4 minutes, and 5

minutes for fire tests No. 1, No. 2, and No. 3, respectively. Jennings (11) states that exposure to more than 1500 ppm of carbon monoxide for more than an hour is dangerous, and that exposure to larger doses for a shorter period is even more dangerous. The actual concentrations at the time of HALON 1301 discharge were in all probability greater than the analyzer 2000-ppm maximum reading. This level indicates that the HF and HBr produced were no more toxic than combustion gasses produced by "normal" fires. The point is that production of toxic gases from HALON 1301 use would cause concern if any of the following conditions exist:

1. HALON 1301 is discharged into space where personnel are present, a fire exists, and concentrations of decomposition products are produced in excess of the lethal limit.
2. HALON 1301 is discharged into a space containing a fire, concentrations of decomposition products are produced in excess of the lethal limit, and the space is open to through areas that are normally inhabited.

DISCHARGE TIME FUNCTION. One of the significant test results was that the production of toxic decomposition products was a function of discharge time rather than fire intensity. The requirement for rapid HALON 1301 discharge requires that a trade-off be made in system design, i.e., personnel normally occupying an area such as a machinery space should vacate the space prior to HALON 1301 discharge. Space abandonment is necessitated not by reason of toxicity of either HALON 1301 or its decomposition products but by the rapid discharge rate. The discharge rate in practice is so rapid that a person or essential equipment in the path of discharge could be injured or damaged. The possibility of injury or damage makes the question of discharge into occupied spaces, with resultant large quantities of toxic HALON 1301 decomposition products, academic for two reasons:

1. Rapid discharge prevents production of large quantities of HF and HBr.
2. Personnel should be out of the area.

ADDITIONAL OBSERVATIONS. Adequate venting arrangements can be incorporated into any installed system design so that problems of misdirected ventilation may be minimized. One further observation concerning HALON 1301 decomposition products is the characteristic sharp acrid odor found in small product concentrations. This odor serves as a "built-in warning system" to individuals close to the fire area.

Chapter IV

SUMMARY AND CONCLUSIONS

The conclusions generated from the fire tests and test results are summarized as follows:

1. HALON 1301 is at least as effective as carbon dioxide for extinguishing large-scale machinery space fires.
2. A discharge time of 10 seconds or less prevents significant decomposition of HALON 1301.
3. The concentrations of HALON 1301 decomposition products are less hazardous than the concentrations of fuel combustion products produced in these fire tests.
4. Adequate mixing can be achieved with a relatively small number of well-positioned nozzles.
5. The low pressure system with nozzles directed downward (toward the bilge) was effective in extinguishing bilge fires. Effective fire extinguishing independent of fire location might require repositioning the nozzles.
6. The length of discharge time, not the severity of the fire, determines the production of HALON 1301 decomposition products.

Chapter V

BIBLIOGRAPHY

This chapter lists the references cited in the other chapters of this report. References are listed in the order cited, and without implying the significance of one reference over another reference.

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